AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

1 of 2

2

PNWD-2227 HEDR
UC-000
DRAFT

Columbia River Pathway Dosimetry Report, 1944-1992

Hanford Environmental Dose Reconstruction Project

W. T. Farris
B. A. Napier
J. C. Simpson
S. F. Snyder
D. B. Shipler

April 1994

Prepared for review and approval by
the Technical Steering Panel and
the Centers for Disease Control and Prevention
under Contract 200-92-0503(CDC)/18620(BNW)

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

Printed in the United States of America

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

The contents of this report were printed on recycled paper

Preface

In 1987, the U.S. Department of Energy (DOE) directed the Pacific Northwest Laboratory, which is operated by Battelle Memorial Institute, to conduct the Hanford Environmental Dose Reconstruction (HEDR) Project. The DOE directive to begin project work followed a 1986 recommendation by the Hanford Health Effects Review Panel (HHERP). The HHERP was formed to consider the potential health implications of past releases of radioactive materials from the Hanford Site near Richland, Washington.

Members of a Technical Steering Panel (TSP) were selected to direct the HEDR Project work. The TSP consists of experts in the various technical fields relevant to HEDR Project work and representatives from the states of Washington, Oregon, and Idaho; Native American tribes; and the public. The technical members on the panel were selected by the vice presidents for research at major universities in Washington and Oregon. The state representatives were selected by the respective state governments. The Native American tribes and public representatives were selected by the other panel members.

A December 1990 Memorandum of Understanding between the Secretaries of the DOE and the U.S. Department of Health and Human Services (DHHS) transferred responsibility for managing the dose reconstruction and exposure assessment studies to the DHHS. This transfer resulted in the current contract between Battelle, Pacific Northwest Laboratories (BNW) and the Centers for Disease Control and Prevention, an agency of the DHHS.

The purpose of the HEDR Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. A major objective of the HEDR Project is to determine possible radiation doses resulting from radionuclides released to the Columbia River.

The HEDR Project work is conducted under several technical and administrative tasks, among which is the Environmental Pathways and Dose Estimates Task. The staff on this task provide the computer codes and dose calculation tools required for estimating doses to individuals who may have been exposed to radioactive releases from the Hanford Site. The dose estimates are the primary objective of the project. Doses calculated for the Columbia River pathway, the subject of this report, are the result of work conducted on various other technical tasks. Estimates of radionuclide releases, Columbia River transport, and environmental accumulation were needed for calculation of radiation doses. Doses are calculated for a number of exposure pathways for the years 1944-1992. Doses are presented for a series of locations on the Columbia River downstream from the Hanford Site.

This report includes a brief description of the methods used to estimate doses to representative individuals who ingested water, fish, or waterfowl from the Columbia River or who spent time swimming in or boating on the river. The information necessary to calculate doses has been documented in other reports published by the HEDR Project. These reports include information on radionuclides released from Hanford reactors (Heeb and Bates 1994), transport of radionuclides in Columbia River water (Walters et al. 1994), accumulation of radioactivity in aquatic organisms

(Thiede et al. 1994) and dose calculation methods and human exposure parameters (Snyder et al. 1994). This dosimetry report is an update of the dosimetry report published earlier (PNL 1991) but is more complete and includes additional data collected by the HEDR Project since 1991. The report presented here fulfills HEDR Project Milestone 0705B.

Summary

The purpose of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate the radiation dose that individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. One objective of the HEDR Project is to estimate doses to individuals who were exposed to the radionuclides released to the Columbia River (the river pathway). This report documents the last in a series of dose calculations conducted on the Columbia River pathway.

The report summarizes the technical approach used to estimate radiation doses to three classes of representative individuals who may have used the Columbia River as a source of drinking water, food, or for recreational or occupational purposes. In addition, the report briefly explains the approaches used to estimate the radioactivity released to the river, the development of the parameters used to model the uptake and movement of radioactive materials in aquatic systems such as the Columbia River, and the method of calculating the Columbia River's transport of radioactive materials.

Potential Columbia River doses have been determined for representative individuals since the initiation of site activities in 1944. For this report, dose calculations were performed using conceptual models and computer codes developed for the purpose of estimating doses. All doses were estimated for representative individuals who share similar characteristics with segments of the general population.

Scope of Work

Doses to representative individuals from reactor releases to the Columbia River have been estimated and presented for the years 1944-1992. Detailed dose estimates are presented for three types of representative individuals: a maximally exposed individual (maximum representative individual), a typically exposed individual (typical representative individual), and an individual exposed on the job (occupational representative individual). Representative individuals are not intended to depict any real individual, but to share the general life-style characteristics of broad segments of the population. Representative individuals can thus provide a basis for evaluating and comparing doses to large cross-sections of the affected population.

Dose estimates were calculated for the three representative individual types in 12 segments of the Columbia River from the Hanford Site to the mouth of the river, and include ingestion of Willapa Bay shellfish and salmon or steelhead caught in the river. Doses were calculated for five radionuclides that together contributed over 94 percent of the total dose: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. Doses in this report are presented as the effective dose equivalent and dose equivalent for the red bone marrow and lower large intestine.

The doses from 1950-1971 have been found to be the largest because of radionuclide releases during those years; thus, doses for this period are estimated with the greatest detail. However, to provide a more complete dose history, additional dose calculations are also presented for 1944

through 1949. Measured doses that were previously published in Hanford annual environmental reports are summarized to complete the dose history for the years 1972 through 1992.

Technical Approach

Estimating doses to the representative individuals from the Columbia River pathway starts with the source term estimate; i.e., an estimate of the radionuclides discharged from the eight single-pass Hanford production reactors into the Columbia River. Using information from the source term estimates, concentrations of the five key radionuclides in the Columbia River water at several downstream locations are calculated by computer simulations of how the radionuclides flow and are transported in the river. Once the radionuclide concentrations are calculated at the various locations, the effects of environmental accumulation can be determined. Dose estimates can then be made for representative individuals.

The computer codes used for the calculations simulate the reactor, the environment, and the human components. Uncertainty, sensitivity, and model validation analyses have been conducted to support this report. The uncertainty analyses helped determine the precision with which dose estimates can be made. The sensitivity analyses have determined the parameters and pathways with the greatest contribution to uncertainty. Model validation compares the model estimates with actual measurements of radionuclides in the environment at the time of the releases, demonstrating the degree to which the model estimates simulate the way events actually occurred.

Results

Four separate Columbia River dose assessments have been conducted during the course of the HEDR Project and are presented in PNL (1991), Walters et al. (1992), Napier (1993), and this document. All four efforts indicate that annual doses to most individuals from river pathways are less than a few millirem per year for any given year and for all locations. Only those individuals who ingested large quantities of Columbia River fish could have received annual doses in excess of one hundred millirem. A complete dose history for a maximum representative (i.e., maximally exposed) individual at Richland, Washington, is shown in Figure S.1. The cumulative dose for this representative individual during the 49-year period from 1944-1992 was estimated to be 1500 millirem. The period, 1950-1971, accounted for most of the cumulative dose from the Columbia River pathway. For the maximum representative individual at Richland, approximately 93 percent (1400 millirem) of the cumulative effective dose equivalent was received during this period. The dose to the maximum representative individual for all other years combined (1944-1949 and 1971-1992) was approximately 100 millirem. The doses calculated for locations near the Hanford Site (e.g., Ringold to Pasco) were larger than those further downriver by factors of 2 to 10, depending on the month and whether the individual was maximally exposed, typically exposed, or occupationally exposed. The decrease in dose to the downriver representative individuals was due to increased dilution and to radioactive decay of key radionuclides as they were being transported in the river. Model validation has shown that the estimated doses for the Tri-Cities area in Washington match well with the actual whole body radioactivity measurements collected during the 1960s.

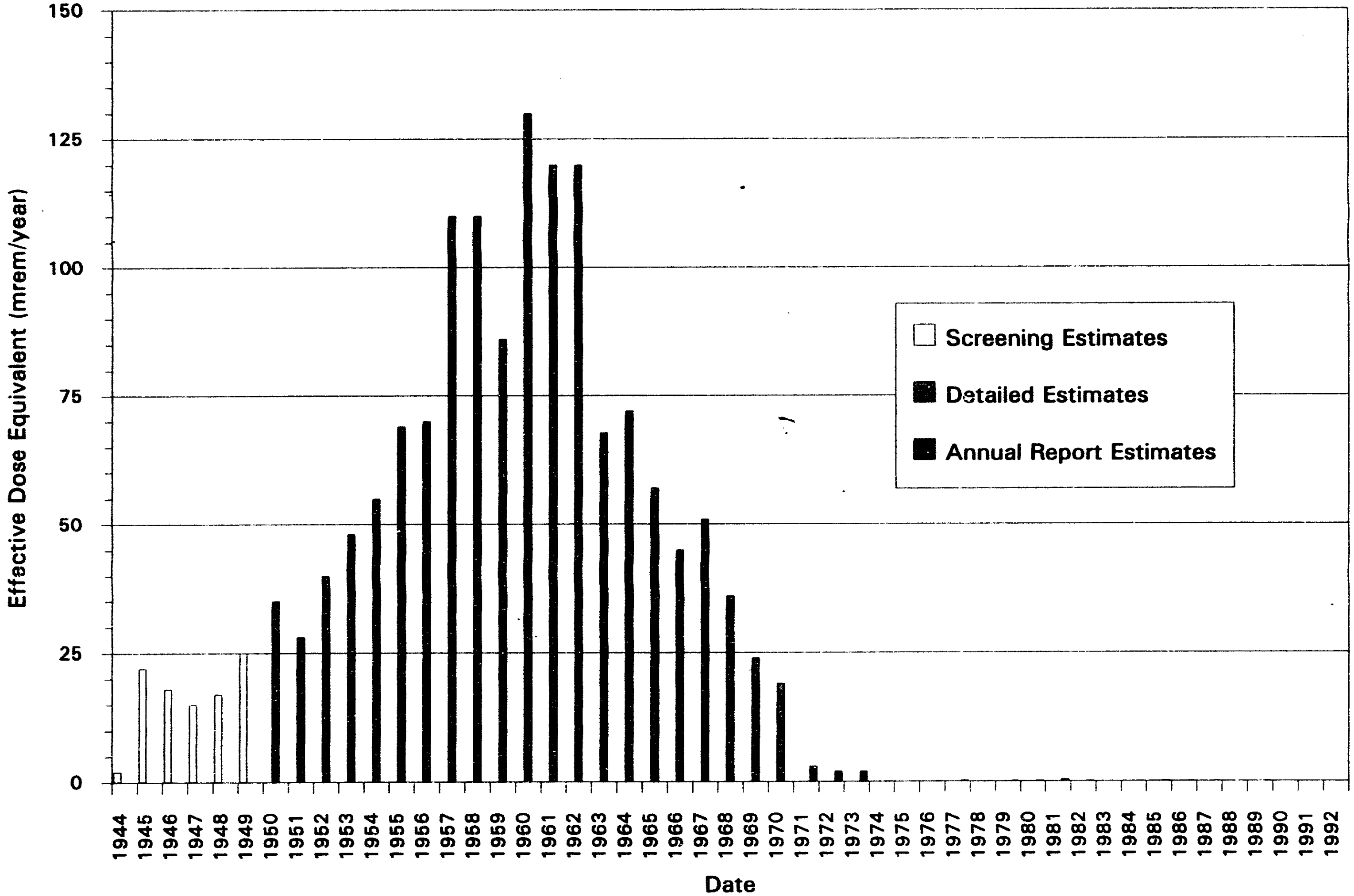


Figure S.1. Dose History for a Maximum Representative Individual at Richland, Washington, 1944-1992

Uncertainty and sensitivity analyses were conducted to estimate the range of possible doses that an individual could have received and the importance of key model parameters. For the three types of representative individuals at any location, the uncertainty range (minimum to maximum) of that person's estimated dose is less than a factor of 10 when the diet is known. The parameters that contribute most to the uncertainty in the estimated dose depend upon the type of individual and exposure location. For example, the most sensitive parameters for a maximum representative individual at Richland, Washington, are the ingestion dose conversion factors (i.e., the factor that translates an amount of a radionuclide ingested into an amount of radiation dose) for zinc-65 and phosphorus-32 and the holdup times (i.e., time between catch and consumption) for fish caught in the river. For a typical representative individual at the same location, the uncertainty in dose is controlled by the uncertainty in the holdup time and the efficiency of the water treatment facility in removing radionuclides from drinking water. The uncertainty in dose estimates for locations farther downriver is controlled almost entirely by the uncertainty of the ingestion dose conversion factors.

Several documents have been published by the HEDR Project that support the material presented in this report. Readers who are interested in more detail on a particular subject should consult the references listed in Table S.1.

Conclusions

- Reliable and useful doses and their uncertainties have been reconstructed for possible exposures of presentative individuals from historical releases of radioactive materials from the Hanford Site.
- The most important means of exposure via the river pathway was consumption of resident fish.
- The most important contributors to dose were zinc-65 and phosphorus-32, respectively, released from the single-pass reactors.
- The highest estimated dose was from resident fish caught in the Columbia River at Ringold, downstream of the Hanford reactors.
- The highest estimated dose was to an adult consuming 40 kilograms (90 pounds) of resident fish from the Columbia River at Ringold (median dose of 140 millirem to the whole body for 1960).
- The highest estimated dose to a typical adult was accumulated during the 1956-1965 time period with 1960 being the highest year (median dose of 5 millirem) at Pasco, Washington.
- The most important contributors to uncertainty in the dose estimates were the dose factor and the bioconcentration factors, respectively.
- Representative individual doses included in this report allow individuals using the Columbia River commercially, for recreation, or as a source of water or foods to estimate their doses.

Table S.1. Key Sources of Information for the Columbia River Pathway

Type of Information	HEDR Project Document
General Project Planning	Shipler, D.B. 1993. *Integrated Task Plans for the Hanford Dose Reconstruction Project, June 1992 Through May 1994*. PNWD-2187 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Radionuclide Releases to the Columbia River	Heeb, C.M., and D.J. Bates. 1994. *Radionuclide Releases to the Columbia River from Hanford Operations, 1944-1971*. PNWD-2223 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Radionuclide Transport in the Columbia River	Walters, W.H., M.C. Richmond, and B.G. Gilmore. 1994. *Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington, to Portland, Oregon, January 1950-January 1971*. PNWD-2225 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Environmental Historical Measurements Related to the Columbia River	Thiede, M.E., D.J. Bates, E.I. Mart, and R.W. Hanf. 1994. *A Guide to Environmental Monitoring Data, 1945 through 1972*. PNWD-2226 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Denham, D.H., R.L. Dirkes, R.W. Hanf, T.M. Poston, M.E. Thiede, and R.K. Woodruff. 1993. *Phase I Summaries of Radionuclide Concentration Data for Vegetation, River Water, Drinking Water, and Fish*. PNWD-2145 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Walters, W.H., R.L. Dirkes, and B.A. Napier. 1992. *Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas*. PNWD-2034 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Methodology for Calculating Doses	Shipler, D.B., and B.A. Napier. 1994. *HEDR Modeling Approach*. PNWD-1983 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Table S.1. (contd)

Type of Information	HEDR Project Document
Equations and Parameter Values Used in Environmental Accumulation and Dose Calculations	Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1994. *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)*. PNWD-2023 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Methods for Conducting Model Uncertainty and Sensitivity Analyses	Simpson, J.C., and J.V. Ramsdell, Jr. 1993. *Uncertainty and Sensitivity Analyses Plan*. PNWD-2124 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.
Previous HEDR Dose Estimates for the Columbia River Pathway	Napier, B.A. 1993. *Determination of Key Radionuclides and Parameters Related to Dose from the Columbia River Pathway*. BN-SA-3768 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. Walters, W.H., R.L. Dirkes, and B.A. Napier. 1992. *Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas*. PNWD-2034 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington. PNL - Pacific Northwest Laboratory. 1991. *Columbia River Pathway Report: Phase I of the Hanford Environmental Dose Reconstruction Project*. PNL-7411 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.
Validation of HEDR Models	Napier, B.A., J.C. Simpson, P.W. Eslinger, J.V. Ramsdell, Jr., M.E. Thiede, and W.H. Walters. 1994. *Validation of HEDR Models*. PNWD-2221 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Glossary

anadromous - fish that live part of their lives in fresh water and part in salt water, living in the ocean, spawning in fresh water.

bioconcentration factor - ratio between the radionuclide concentration in biota to the radionuclide concentration in the water in which they live and feed.

biota - plants and animals.

body burden - amount of a given radionuclide in humans, typically measured in nanocuries.

boxplot - graphical representation of the distribution of values in which a box shows the middle 50 percent of the distribution and the "whiskers" indicate the lower and upper 5 percent of the distribution.

CHARIMA - CHArriage des RIvieres MAiliees, computer code that models sediment transport in multiple channel river systems.

Ci - abbreviation for curie.

code - computer implementation (program) of equations.

composite sample - sample composed of small portions collected from several locations or from a single location over an extended time period.

concentration - amount of a specified substance (e.g., a radioactive element) in a unit amount of another substance (e.g., river water).

confidence interval - statistical range with a specified probability that a given parameter lies within the range.

CRD - Columbia River Dosimetry, computer code used to estimate doses to individuals.

curie - unit of radioactivity corresponding to 3.7×10^{10} (37 billion) disintegrations per second (abbreviated Ci).

deterministic - estimation method where a single-point estimate is calculated (contrast with "stochastic").

dose - radiation dose; often distinguished as absorbed dose, dose equivalent, or effective dose equivalent.

> **absorbed dose** - amount of energy deposited by radiation in a given amount of material, such as tissue; measured in rad.

dose equivalent - quantity calculated to compare relative biological effectiveness of different kinds of radiation, using a common numerical scale; determined by multiplying absorbed dose by a quality factor and other modifying factors; measured in rem.

effective dose equivalent (EDE) - quantity that is the sum of 1) the committed effective dose from internal deposition of radionuclides in the body and 2) the effective dose from external radiation received during a particular year; measured in rem.

dose factor - factor that describes the amount of radiation dose received from a given intake of radioactivity.

effluent plume - spread of contaminants in air, surface water, or ground water released from a point source.

empirical - results obtained by relying on observation or experiment.

first-order predator - fish that consume other fish; includes perch, crappie, punkinseed, and bluegill.

fuel element - aluminum-clad rod used in Hanford reactors.

fuel-element failure - rupture of a fuel element, leading to an usually high radioactive contamination of the cooling water.

grab sample - sample collected from a single location at a specific time.

gross beta - total activity of beta-emitting radionuclides that could not be distinguished separately by instrumentation and did not include volatile beta-emitting radionuclides.

half-life - time required for an initial number of radioactive atoms to be reduced to half that number by transformations.

histogram - bar graph of a frequency distribution in which the widths of the bars are proportional to the classes into which the variable has been divided and the heights of the bars are proportional to the class frequencies.

isotope - one of two or more atoms having the same atomic number but different mass numbers.

LLI - lower large intestine.

mean - average value of a set of numbers.

median - middle value in a series of values arranged in order of size.

model - conceptual representation of physical/biological processes.

modules - sections of a computer code.

Monte Carlo technique - method that represents the effect of uncertainty in one or more contributing parameters on the overall uncertainty by randomly sampling distribution functions which express parameter uncertainty.

mrad - millirad, one-thousandth of a rad.

mrem - millirem, one-thousandth of a rem.

neutron flux - rate of neutron bombardment.

omnivore - fish that eat both plants and animals; includes bullheads, catfish, suckers, whitefish, chiselmouth, chub, sturgeon, minnows, and shiners.

picocurie - one-trillionth of a curie.

process tube - aluminum tube that held the uranium fuel elements and cooling water in Hanford reactors.

rad - radiation absorbed dose, unit of measurement used to describe absorbed dose.

radionuclide - isotope of an element that exhibits radioactivity.

RBM - red bone marrow.

realization - particular pass through a Monte Carlo simulation in which all stochastic parameters have been assigned a value; the simulation represents a "possible reality."

rem - roentgen equivalent man, unit of measurement used to describe dose equivalent.

representative individuals - individuals sharing similar characteristics significant to estimating dose; in this report, three types of representative individuals are defined: maximum, occupational, and typical.

> **maximum representative individual** - significant user of the Columbia River who spent time in or on the river and ingested maximum or near maximum amounts of fish and waterfowl.
>
> **occupational representative individual** - individual who was exposed to the Columbia River only in the course of work and ingested salmon and shellfish but no resident fish.
>
> **typical representative individual** - individual residing near the Columbia River who ingested no resident fish or waterfowl.

second-order predator - predatory fish that consume other fish; includes bass, trout, and squawfish.

sensitivity - determination of the parameters and pathways that contribute most to uncertainty in calculations.

single-pass reactor - plutonium-production reactors that did not recirculate Columbia River water but instead discharged it directly through retention basins to the Columbia River.

source term - amount of radioactivity (curies) of a radionuclide released to the environment from a facility at a given time.

stochastic - method of estimating possible values by using a range of possible input parameters to arrive at a corresponding range of possible results (contrast with "deterministic").

STRRM - Source Term River Release Model, computer code that provides estimates of monthly releases of radionuclides from Hanford reactors to the Columbia River.

transmission factor - amount of radioactivity that remains after municipal water treatment.

uncertainty - measure of the precision with which dose estimates can be made.

validation - model validation; comparison of estimated values to historical measurements as a test of the reliability of the model estimates; successful model validation makes credible those values that need to be estimated when no historical measurements are available.

WSU-CHARIMA - Washington State University modified CHARIMA computer code; modification allowed for radionuclide decay.

Contents

Figures

Tables

1.0 Introduction

The Hanford Site in southeastern Washington State was selected in 1943 as the location for the facilities used to produce plutonium for atomic bombs during World War II. Three plutonium production reactors (B, D, and F) began operating in 1944 and 1945. These reactors withdrew water from the Columbia River and, after extensive treatment, used that water to cool the core of the reactors. This water was first discharged to retention basins and then, after a holdup time, discharged directly to the Columbia River. These reactors were called "single-pass" reactors because they discharged effluent cooling water directly to the river rather than recirculating it. After the end of World War II in 1945, the reactors continued to be used to produce plutonium. From 1949 through 1963, six new reactors (H, DR, C, KW, KE, and N) began operating. The N Reactor differed in design from the earlier reactors in that cooling water was recirculated through the reactor core instead of being discharged directly to the Columbia River. Radionuclide emissions from the N Reactor were not studied as part of this effort. However, doses from the N Reactor are included in the dose estimates presented in this report.

The availability of relatively pure Columbia River water for cooling was one of the reasons for locating plutonium production at the Hanford Site (Groves 1962). The use of river water to cool the reactors resulted in the release of radionuclides to the Columbia River. Releases of radionuclides to the ground from nuclear facilities in the Hanford 200 East and West areas resulted in smaller releases to the Columbia River (Freshley and Thorne 1992). The B Reactor was shut down by 1968. By January 1971, all of the other single-pass reactors had been shut down as well, leaving the N Reactor the only plutonium-production reactor operating at the Hanford Site. The N Reactor was shut down in 1987.

Individuals who drank water from the Columbia River, ate food affected by the river, or used the river for recreational or occupational purposes would have received a radiation dose from Hanford emissions. The magnitude of that dose depends on the amount of individual use of the river and on the particular year that use occurred. Doses may have also been received by individuals who did not directly access the Columbia River. Some dose could have been acquired by the ingestion of salmon, whose migration route was the Columbia River but which were caught in the Pacific Ocean, and the ingestion of oysters from Pacific Ocean estuaries near the Columbia River.

A feasibility study for the Columbia River pathway was conducted in 1991 to determine if a retrospective assessment of the Columbia River pathway was possible and to determine the magnitude of possible radiation doses. The scope of the feasibility study was narrow and included limited time periods and locations. The general findings of the feasibility study were that sufficient historical information could be retrieved and reconstructed, computer models for dose assessment could be developed, and the modeling approach could produce credible dose estimates (PNL 1991).

1.1 Purpose

The purpose of the Hanford Environmental Dose Reconstruction (HEDR) Project is to estimate the radiation dose that representative individuals could have received as a result of radionuclide emissions since 1944 from the Hanford Site. This dose assessment effort expands and refines the modeling approach used in the feasibility study dose assessment (PNL 1991). The time period covered in the feasibility study was expanded from 1964-1966 to 1944-1992 in this study. The number of feasibility study locations covered was also expanded from 5 locations between the reactors and McNary Dam to 12 locations from the reactor areas to near the mouth of the Columbia River. In addition to expanding the time periods and locations, several refinements were made to the feasibility study approach. These refinements were recommended by the HEDR Technical Steering Panel (TSP) and include a more detailed estimate of radionuclide releases from the reactors, an enhanced river transport assessment, and a more complete collection of historical measurements.[a] In general, no changes were made to the fundamental methods used to estimate the feasibility study doses.

1.2 Scope

This report estimates the doses that could have been received by three types of representative individuals as a result of radionuclide releases from Hanford production reactors to the Columbia River from 1944-1992: maximally exposed individual (referred to in the report as a **maximum representative individual**), a typically exposed individual (**typical representative individual**), and an occupationally exposed individual who was not a worker at the Hanford Site (**occupational representative individual**). Detailed dose estimates for five radionuclides (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) for the time period of largest releases (1950-1971) were estimated on a monthly basis for the three types of representative individuals. The dose estimates are based on radionuclide concentrations in 12 distinct segments of the Columbia River and include ingestion of Willapa Bay shellfish and salmon and steelhead from anywhere in the river. Radiation doses were much lower during 1944-1949 and 1972-1992. In order to show relative dose, this report provides annual doses for a maximum representative individual at the highest impact location during these years.

1.3 Preview of Report

Section 2.0 summarizes the data quality objectives for estimating radiation doses. Section 3.0 describes the technical approach used in calculating the dose to individuals from the Columbia River pathway. This section includes a discussion of the source term, river transport, environmental accumulation, and dose assessment procedures. The equations used to estimate dose are also presented in this section. Sample doses for 1944-1992 are presented and discussed in Section 4.0. Section 5.0 includes a discussion of model reliability, including parameter uncertainty and sensitivity analysis and validation studies of the models. Conclusions are presented in Section 6.0. A detailed table showing doses to representative individuals for January 1950 through January 1971 is included in the Appendix.

(a) Memorandum (HEDR Project Document No. 11920015), "Recommendations for Further River Pathway Work, FY93," from P.C. Klingeman (TSP) to TSP Members and D.B. Shipler (BNW), September 28, 1992.

2.0 Data Quality Objectives

The data quality objectives (DQOs) for estimating radiation doses from the Columbia River pathway are defined in Shipler (1993). The doses calculated and presented in this document are based on the data provided by other tasks and subtasks in the HEDR Project. The DQOs developed by other tasks bear on the overall quality of the estimated dose. The DQOs for the other HEDR tasks are also presented in Shipler (1993).

2.1 Accuracy

The accuracy objective is to estimate doses using models that have been evaluated and refined by validation studies and sensitivity/uncertainty analyses. Doses presented in this document have been estimated by using models and derived computer codes that have been tested for numerical accuracy as well as for their ability to generate results that compare with historical measurements. The validation of all the HEDR models is documented in Napier et al. (1994). That report states that, in general, the comparisons show relative agreement and that most of the calculated results show order-of-magnitude agreement with the historical measurements. The final determination of accuracy has been made by HEDR Project and TSP review of this report and of Napier et al. (1994). Uncertainty and sensitivity analyses were conducted to estimate the range of possible doses and to determine those parameters that contribute most to the uncertainty in doses.

2.2 Precision

The precision objective is to quantify the precision of dose estimates for a real individual by conducting uncertainty analyses using estimated parameter uncertainties and appropriate error propagation procedures. The uncertainty analyses were conducted using random-sampling techniques that have been approved by the TSP. The results of the analyses are presented in Section 5.0 of this report. The final determination of precision has been made by project and TSP review of this report.

2.3 Completeness

The HEDR modeling approach, developed by Shipler and Napier (1994), was used to estimate doses based on the quality and abundance of historical data available for source term and environmental transport radionuclide measurements. The doses presented in this report cover the history of Hanford Site operations from 1944 through 1992. The potential doses from 71 radionuclides were investigated by Napier (1991b), and Napier (1993) further evaluated 19 radionuclides identified as major contributors to radiation dose. Five radionuclides, contributing over 94 percent of the total dose, were included in the final dose calculations. None of the other radionuclides contributed over 2 percent of the total dose. Also, six additional radionuclides were included in source term estimates because they were needed for river transport validation or were of particular interest to the TSP. Napier and Brothers (1992) evaluated the exposure pathways to be included in the final dose calculations and presented recommendations to the TSP based on "value of information." Pathways determined to be minor contributors to dose were not included in the final calculations. The estimated doses include doses received along 12 segments of the Columbia River downstream of the Hanford Site in addition to doses from the ingestion of shellfish from the coastal waters of the Pacific Ocean and salmon and steelhead from anywhere in the river.

2.4 Representativeness

The representativeness of dose estimates was determined by comparing environmental historical measurements with the estimates of the HEDR models. The doses presented in this document have been converted to body burden estimates and compared, where possible, to measured human radionuclide body burdens. This comparison is documented in Napier et al. (1994), and a brief summary is presented in Section 5.0 of this report. In general, estimated body burdens were within the range of measured values.

2.5 Comparability

A comparison of the estimated doses presented in this report has been made with doses calculated earlier in the HEDR Project and is presented in Section 4.1.6. The doses are comparable to other doses calculated by the HEDR Project and other investigators. Estimated doses were also compared with doses presented in annual environmental reports produced by Hanford contractors since 1957. Again, the doses presented in this report are very similar to the doses presented in the earlier annual monitoring reports. The small differences in doses were primarily due to different assumptions regarding internal dosimetry or human ingestion values. When similar assumptions were made, the estimated doses are nearly identical.

3.0 Technical Approach

This section outlines the technical approach used to estimate radiation doses to individuals who may have used the Columbia River as a source of drinking water or food or who may have used the river for recreational or occupational purposes. The section briefly addresses the approach used to estimate the quantity of radioactivity released to the river, the transport of radioactive materials by the Columbia River, and the development of parameters to simulate the uptake and movement of radioactivity in aquatic systems. These methods and parameters are described in much greater detail in Heeb and Bates (1994), Walters et al. (1994), Snyder et al. (1994), and Thiede et al. (1994).

Measured and Modeled Dose Estimates. The first steps in estimating doses involve determining the radionuclide concentrations of the Hanford reactor effluents that were discharged into the river. These concentrations can then be analyzed to determine radionuclide concentrations in various sections of the Columbia River downstream from Hanford. These data are available in the form of historical measurements or through computer simulation. Once the radionuclide concentrations in the river at selected locations are known, the effects of environmental accumulation in aquatic biota and use of the river by humans can be estimated. Doses can then be estimated using food consumption and lifestyle information for representative individuals. Figure 3.1 outlines the computer modeling process for the Columbia River pathway.

Because it was not possible to estimate dose for the Columbia River pathway based entirely upon historical measurements, the TSP determined that modeling was the preferred method for estimating dose.[a] Thus, all steps in the dose estimation process, from source term determination to dose assessment, involve the use of computer models. These models are required for two reasons: 1) measurements of radionuclide concentrations in important environmental media (i.e., water, resident fish, salmon, and shellfish) do not exist for all necessary locations and time periods (Napier and Brothers 1992; Walters et al. 1992; Denham et al. 1993) and 2) environmental monitoring during later years yielded radioactivity measurements below the detection limit of the measuring instrumentation. Napier and Brothers (1992) investigated the level of detail in modeling and recommended the use of historical measurements supplemented by modeling.

The TSP further recommended[a] that most dose estimating effort be expended for the years from 1956-1965 (the period during which radionuclide releases to the Columbia River are known to have been highest) and that the effort expended to estimate doses for the periods prior to 1955 and after 1965 be appropriate to the releases.

Dominant Radionuclides/Pathways. Selection of radionuclides and pathways for detailed examination were first addressed by Napier (1991b), who ranked the doses from 71 radionuclides identified in detailed measurements made in 1956, 1964, and 1968, plus those estimated to be released during fuel failures. The pathways addressed were drinking water, recreation on or near contaminated water (swimming, boating, or shoreline activities), and consumption of fish. Also addressed were pathways from irrigation with contaminated river water, including consumption of

(a) Memorandum (HEDR Project Document No. 11920015), "Recommendations for Further River Pathway Work, FY93," from P.C. Klingeman (TSP) to TSP Members and D.B. Shipler (BNW), September 28, 1992.

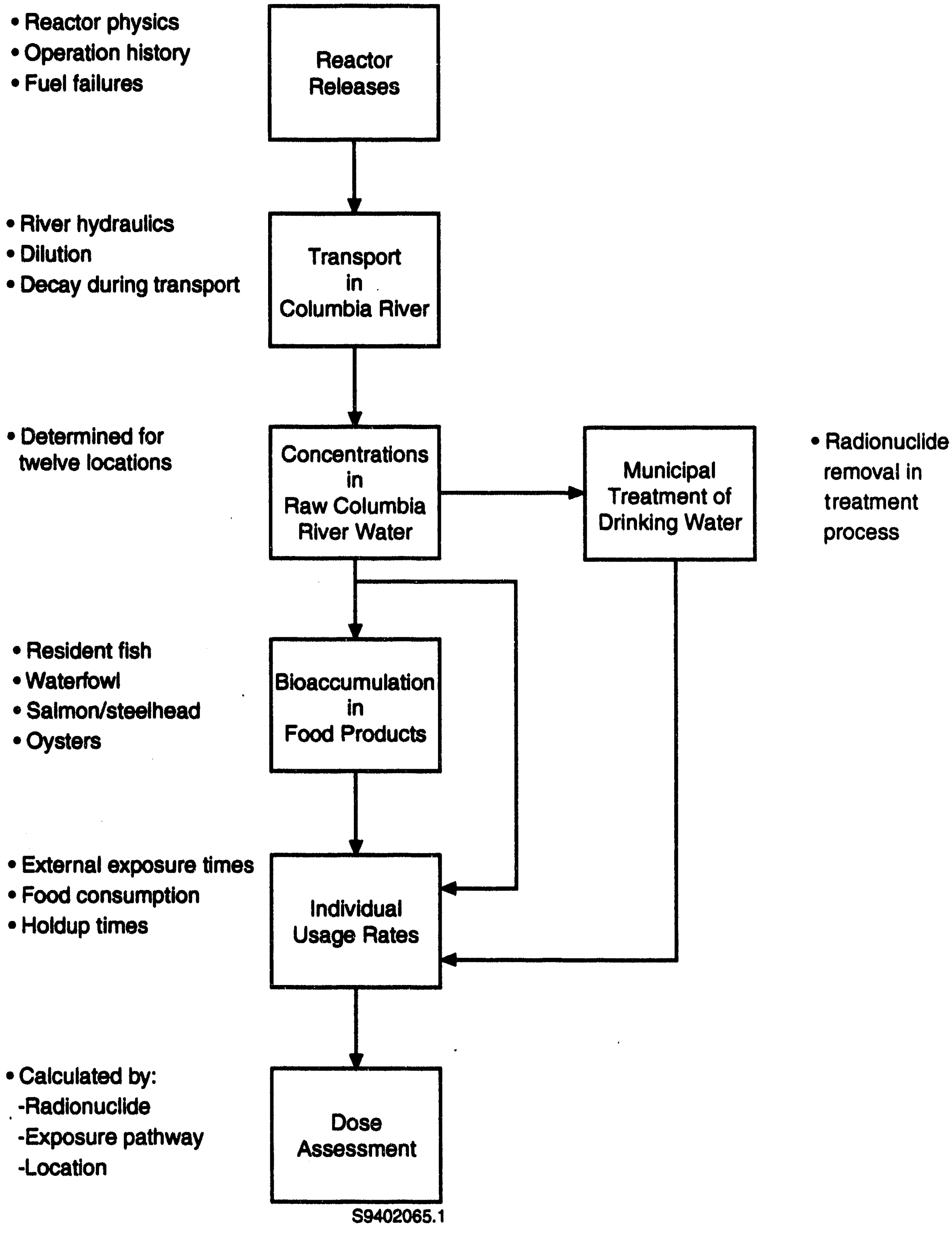


Figure 3.1. Columbia River Pathway Modeling Process

irrigated produce and animal products, exposure to soils contaminated by the water, and inhalation of resuspended dusts from such soils. Of the radionuclides originally investigated, five were identified as important for their potential radiation dose (phosphorus-32, copper-64, zinc-65, arsenic-76, and neptunium-239) with four more considered to be of marginal importance (sodium-24, scandium-46, chromium-51, and manganese-56) (Napier 1991b, p. vii). The irrigation-related pathways were shown to be of secondary importance.

In addition, Freshley and Thorne (1992) evaluated the contribution of radionuclides to the Columbia River via groundwater from the Hanford Site. This investigation dealt with potential doses via the river pathways as defined in Napier (1991b), as well as the potential doses from riparian wells (Freshley and Thorne 1992, pp. 8.1-8.6) and offsite wells (Freshley and Thorne 1992, pp. 6.81-6.84). The general conclusion of this report was that these sources contributed minimal amounts to individual dose.

The model design specification in the HEDR feasibility study (Napier 1991a) considered the results of the previous two studies, and included in the feasibility study calculations eight radionuclides (all those suggested in Napier [1991b] except scandium-46, which was omitted because of lack of data and marginal significance to dose) and all of the direct river pathways of drinking, recreation, and fish consumption. The doses resulting from this modeling were presented in the *Columbia River Pathway Report* (PNL 1991, p. 2.13).

The TSP adopted "dose decision levels," the lower threshold values below which research efforts to define dose should be minimized.[a] These were incorporated into the *HEDR Modeling Approach* (Shipler and Napier 1992, p. 17) for the Columbia River pathway, by stating, "If, upon consideration, it is determined that any given pathway has the potential to add more than 5% to the total dose for any individual at a time when the dose exceeds the TSP guidelines, it will be...added to the main models...."

Walters et al. (1992, Section 10) re-investigated all major river-related exposure pathways. The pathway of consumption of resident fish was again found to dominate the results. Consumption of anadromous fish was noted to be a lesser contributor. The irrigation-related pathways were again shown to result in small doses. Napier and Brothers (1992) combined the results of the Walters et al. (1992) dose analysis, the TSP dose decision levels, and a value-of-information analysis to provide a set of recommendations to the TSP for further work. Napier and Brothers (1992, pp. 6.1-6.6) recommended that the pathways related to irrigation, shoreline exposure, and inhalation be dropped, because they contributed only small amounts to the total dose. They recommended including resident fish, anadromous fish, waterfowl, oysters, drinking, and swimming/boating pathways in the final calculations.

A set of interim source terms was made available by efforts of TSP member, M. A. Robkin, in early 1993. Napier (1993) addressed the pathways recommended in Napier and Brothers (1992) using this source term data. As a result of this computation, the final selection of five radionuclides

(a) Unpublished report (HEDR Project Document No. 12910094), "Scoping Document for Determination of Temporal and Geographic Domains for the HEDR Project," by B. Shleien (TSP), adopted by the TSP at meeting on February 20-22, 1992, p. 9.

(sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) was made.[a] This scoping study also provided supporting data for the selection of the locations for which doses are reported (Napier and Brothers 1992). Napier (1993, Appendix B) also provided a summary of doses presented in all Hanford Site annual environmental monitoring reports from 1956 through 1972. These summaries helped define the time period for which calculations are made.

Thus, the five key radionuclides used as input to the dose calculations were sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. Although it did not contribute significantly to dose, chromium-51 was used for validating the modeling of the river transport of radionuclides because it was virtually always present in detectable concentrations. For the sake of completeness, the source terms for manganese-56, gallium-72, yttrium-90, iodine-131, and gross beta were also estimated even though these radionuclides did not contribute significantly to dose.

Section 3.1 explains the "source term" model used for determining the radionuclide concentrations at their point of origin; i.e., as they entered the Columbia River at Hanford. The section also includes an explanation of the physical mechanisms by which the radionuclides entered the river and which radionuclides were chosen for input to other models that estimate transport down river, concentrations in foods affected by the Columbia River, and finally the doses experienced by persons exposed through various pathways. The following subsections explain the methods used in the transport, concentration, and dose assessment models (Sections 3.2, 3.3, and 3.4, respectively).

3.1 Source Term Model

The possible consequence of radionuclide releases to individuals has been addressed by starting with estimates of the amount and timing of those releases (i.e., the source term). Determining the source term is necessary when concentrations of radionuclides in environmental media are too low to be measured or when monitoring was not comprehensive enough to address all radionuclides, locations, and exposure pathways. Source term release estimates were derived from the large amount of information that exists in government- and contractor-generated documents, plus articles in various technical journals concerning radioactive releases to the Columbia River from Hanford reactor operations. The HEDR Project has produced radionuclide estimates on a monthly basis for 11 radionuclides, plus gross beta activity, over the entire period of single-pass reactor operation, 1944-1971 (Heeb and Bates 1994).

Source term estimation covers the radionuclides released during the operation of the eight Hanford Site single-pass production reactors: B, C, D, DR, F, H, KE, and KW. N Reactor, which recirculated the primary cooling water within its core and did not discharge directly to the river, was not included in the scope of Heeb and Bates (1994). N Reactor releases are, however, included in the Hanford annual report doses presented in this report.

(a) Letter (HEDR Project Document No. 07930232), "Key Radionuclides for River Pathway," from J. E. Till (TSP) to D. B. Shipler (BNW), April 12, 1993.

The information used to reconstruct radionuclide releases to the Columbia River comes from measurements of radionuclide concentrations in reactor effluent before the effluent was discharged to the river. The reconstruction also depends on a quantitative reconstruction of reactor operations to determine the amount of radioactive materials produced by the reactors. This reconstruction has been accomplished and documented by Heeb and Bates (1994). The information was obtained from monitoring records of Hanford effluent. Although such data were plentiful, the number of radionuclides that were monitored and the time periods covered were limited. The data in the historical documents are generally reported on a monthly basis. Although some information does exist on daily reactor operations, the information does not cover the entire 1944-1971 time period. Therefore, Heeb and Bates (1994) present source term information by the month. This approach has been deemed adequate for estimating annual doses. Where gaps in information occur, reasonable estimates of the missing historical measurements were supplied by using statistical analysis of available effluent measurements together with Monte Carlo uncertainty modeling.

3.1.1 Mechanism for Source Term Releases to River

Radioactive materials generated at the Hanford Site were produced primarily by fission of uranium in the reactors, activation of nonradioactive materials, and by fission and activation of naturally occurring uranium-238 in reactor coolant water during reactor operations.

Water from the Columbia River was pumped into a water treatment plant where chemicals were added to adjust the pH, decrease turbidity, and inhibit corrosion of the supply piping and reactor process tubes. The processed river water was then filtered, held in clear wells, and pumped into large holding tanks. From the tanks, it was pumped to the reactor inlet to be used as reactor cooling water.

The cooling water passed from the inlet piping into the gap between the fuel-element surface and the process tube. During its brief passage through the reactor core region (1 to 2 seconds), water at the inlet river temperature (0 to 20°C) was heated to over 100°C in the highest-powered tubes. The cooling water was also subjected to a neutron flux of between 10^{13} and 10^{14} neutrons per square centimeter per second. This neutron flux caused trace impurities in the cooling water to be converted into radioactive species. This process is called neutron activation and accounts for the bulk of the radioactive emissions to the Columbia River. The hot effluent water (bulk temperature as high as 95°C) was discharged from the reactor into external retention basins located near the Columbia River. After cooling thermally and allowing time for the shortest-lived radionuclides to decay, the basin water was discharged to the Columbia River. The capacities of the retention basins were designed to allow a nominal holdup time of 2.4 to 4 hours. With design modifications to increase reactor power in 1957, however, the reactor bulk flows in the B, D, DR, F, and H reactors were increased to almost three times the original designed flows. This resulted in holdup times nearer to 1 hour, which decreased the time allowed for radioactive decay.

As reactor operation continued, films of oxides and entrained materials built up on both process tubes and fuel elements. Beginning in 1945, slurries of abrasive diatomaceous earth were injected into the inlet cooling water during full power operation. This material mechanically removed some of the film from fuel elements and process tubes. These purges continued until final shutdown in 1971. Because the film being removed contained radionuclides, purges resulted in temporarily increased radioactive discharges to the Columbia River. However, radionuclide releases to the river during diatomaceous earth purges have been determined to be minor compared to releases from routine operations, fuel-element failures, and activation of corrosion products in the process tubes (Heeb and Bates 1994).

Hanford experienced nearly 2000 fuel-element failures in the eight single-pass reactors. A fuel-element failure occurred when the aluminum cladding was breached, allowing coolant water direct access to the irradiated uranium. The result was a release of fission products and bred actinides to the effluent water. Every attempt was made to remove the fuel element with the failure as soon as possible. The reactor was shut down as soon as a fuel-element failure was indicated. For purposes of the HEDR Project, information on the reactor, date, and classification of each failure was extracted from Hanford reports. This information was used to estimate the release contributions of iodine-131 and neptunium-239 from fuel-element failures. These two radionuclides, the first a fission product and the other a neutron capture product of uranium-238, were widely used as indicators of fuel-element failures. Heeb and Bates (1994, pp. 4.27 and 4.29) estimated that 44.9 percent of the iodine-131 and 11.9 percent of the neptunium-239 releases came from fuel-element failures. Most of the iodine-131 and neptunium-239 resulted from natural uranium in the Columbia River water.

3.1.2 Radionuclide Release Estimates

Figure 3.2 shows the annual releases of the five key radionuclides used for dose calculations. These totals (in curies/year) are the median values of 100 stochastic realizations (Heeb and Bates 1994). Monte Carlo stochastic modeling was used to estimate uncertainties in the source term release estimates. The estimates of radionuclide releases to the Columbia River include the calculated radionuclide decay from the time of release from the reactors to the time of actual discharge to the river. A complete description of the source term uncertainty is presented in Heeb and Bates (1994).

Figure 3.3 shows the activity of the five key radionuclides that existed throughout the Columbia River and adjacent area in the Pacific Ocean. Because of the very short (15-hour) half-life of sodium-24, no more than 3500 curies of sodium-24 were ever detected at any time, even though nearly 1,400,000 curies were released during 1960 alone. Conversely, almost 80,000 curies of zinc-65, the most long-lived of the five radionuclides, existed (mainly in the Pacific Ocean) during the highest year of 1962, although no more than 56,000 curies of this radionuclide were ever released in one year. The effect of radioactive decay is demonstrated by Figures 3.2 and 3.3. The amount of radionuclides released does not correlate to radiation dose.

3.2 River Transport Model

A computer model of the flow and transport of Columbia River water was used to provide monthly average concentrations of radionuclides at specific locations along the river. The model, documented by Walters et al. (1994), estimates the radioactivity in the Columbia River after the river received cooling water effluent from the eight Hanford single-pass reactors. The reconstruction of historical water concentrations is limited to the area downriver from the reactors where the cooling water was returned to the river. Specifically, the concentrations of radionuclides are estimated from Priest Rapids Dam downstream to just below Portland, Oregon. Within that length of river, the TSP

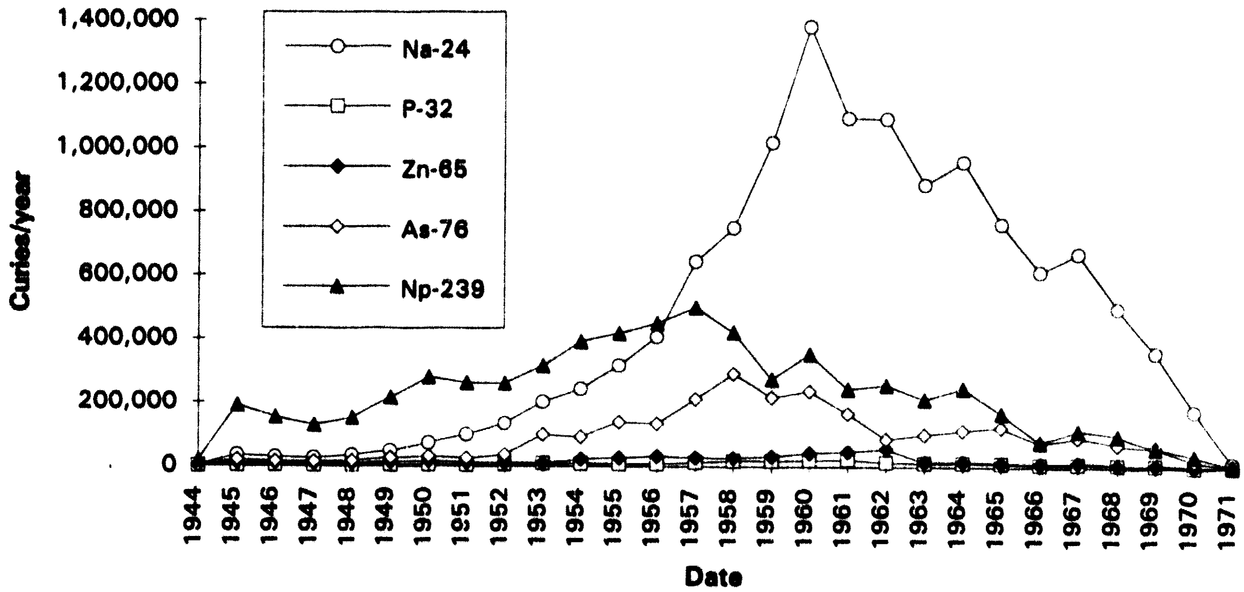


Figure 3.2. Key Radionuclides Released to the Columbia River by Year, 1944-1971

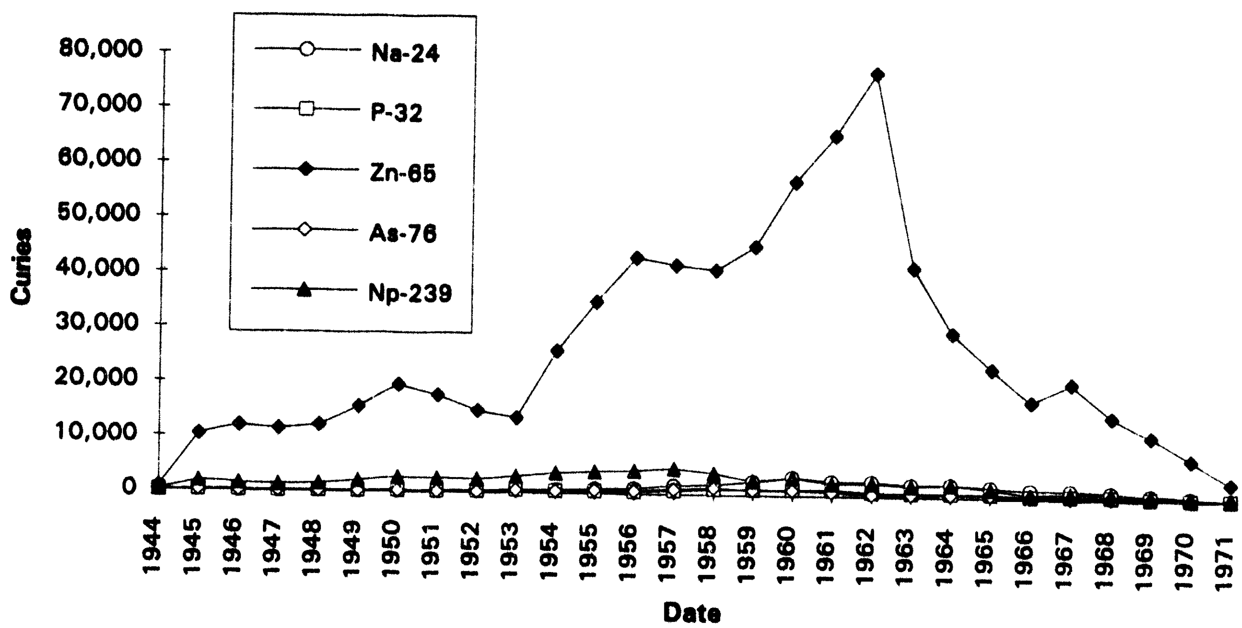


Figure 3.3. River/Ocean Radionuclide Burden, 1944-1971

selected 12 locations where radionuclide concentrations were to be reconstructed, beginning with January 1950 and extending through January 1971.[a] Figure 3.4 shows the domain of the Columbia River pathway computer model, including the Columbia River, the Hanford Site, and the locations used for reconstruction of radionuclide concentrations.

3.2.1 Development of the Columbia River Transport Conceptual Model

An extensive Columbia River literature review was conducted and reported in Walters et al. (1992). That report provides a brief description of reactor operations, effluent water composition, and routine and accidental radionuclide releases. The report also discusses special studies conducted by Hanford contractors of reactor effluent plume dispersion, shoreline radiation surveys, and downriver travel times as well as routine monitoring results and preliminary dose calculations.

Based on an evaluation of data and information found in Hanford and offsite literature, the TSP recommended[b] that surface-water concentrations be determined for use in dose estimates. Walters et al. (1992) recommend that a one-dimensional hydraulic model be used to estimate the route of effluent from the reactors to downstream locations where dose is to be estimated. The TSP further recommended that reactor source term data be used with the hydraulic routing model to reconstruct radionuclide concentrations because of insufficient Columbia River historical measurements. Measurements downstream from Pasco, Washington, were very limited or nonexistent, and before 1958 only gross beta measurements were available at any location on the river.

Further recommendations by the TSP were that the effects on water concentrations of the reactor effluent plume and the sediment uptake and release of radionuclides should be based upon the results from past field studies and historical measurements and not directly calculated by the model. A complex effluent plume analysis was not needed because the horizontal mixing width can be adequately determined using a simple hand calculation and vertical mixing occurs rapidly near the reactor outfalls. For sediment uptake effects, a simple empirical approach using correction factors developed from experiments with the selected model estimates and historical measurements. The effects of the plume were to be limited to the Hanford Reach, while the sediment uptake effects may have extended the length of the Columbia River.

Hydraulic computer modeling required the use of a one-dimensional, unsteady flow model capable of routing water and radionuclide releases downstream from the Hanford reactors for the required time span and locations. The code selected for the Columbia River transport work was CHARIMA (CHArriage des RIvieres MAillees) which simulates sediment transport in looped river systems (Holly et al. 1993). CHARIMA was selected because it fulfills the following modeling requirements specified by the TSP (Farris 1993):

(a) Letter (HEDR Project Document No. 07930224), "HEDR Project Locations for Calculation of Radionuclide Concentrations in the Columbia River (14)," from D. E. Walker, Jr. (TSP) to W. A. Bishop (TSP), April 2, 1993.

(b) Memorandum (HEDR Project Document No. 11920015), "Recommendations for Further River Pathway Work, FY93," from P.C. Klingeman (TSP) to TSP Members and D.B. Shipler (BNW), September 28, 1992.

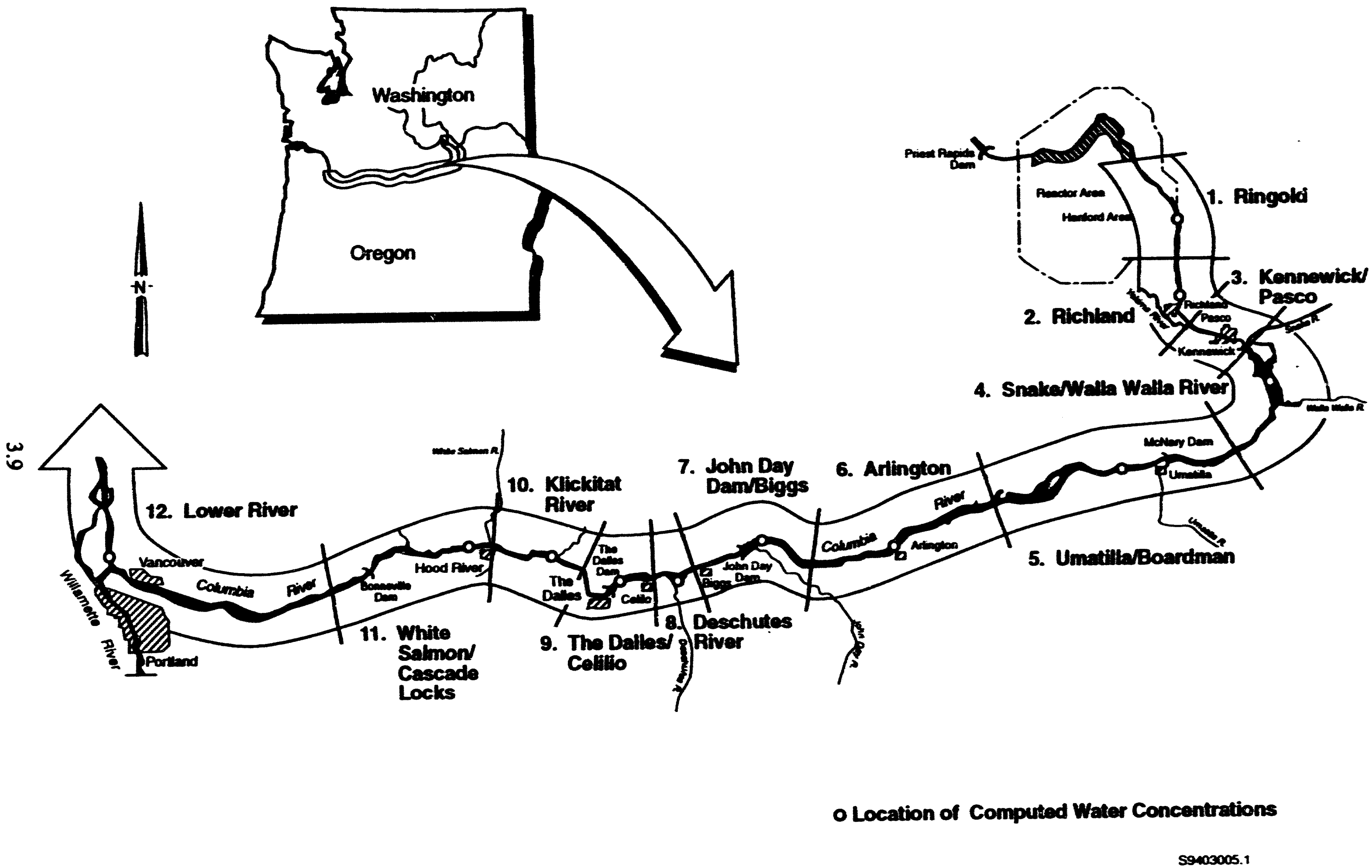


Figure 3.4. Columbia River Pathway Model Study Area

- use monthly or weekly source term data
- use monthly, weekly, or daily river flow data
- establish the point of complete effluent plume mixing below the reactors
- assume complete mixing below McNary Dam
- make simple radionuclide decay corrections for travel time in river water downstream
- make simple assumptions about water/sediment interactions
- use one-dimensional analysis (longitudinal only)
- use unsteady flow and reservoir routing
- use a simple empirical approach for sediment uptake/release.

Moreover, CHARIMA can accommodate tributary inflows, multiple channels within a river, and the presence of dams and reservoirs. It also has the capability to route contaminants to any specified location.

CHARIMA is a finite-difference code that simulates unsteady flow (flood wave) hydraulics and nonuniform sediment transport in open channel (unimpounded) systems such as rivers and canals. The code can simulate the operation of dams and reservoirs and input a constituent (such as a contaminant or heat) in the routing scheme. For the Columbia River computations, the CHARIMA code was modified to allow for radionuclide decay. The modified code is called WSU-CHARIMA to differentiate it from the acquired version. The sediment transport capabilities of the CHARIMA code were not used because the required amount of historical data for the Columbia River were not available.

3.2.2 Model Validation

The Columbia River model was validated by a process that compared historical measurements with those estimated by the model. The validation of the water concentrations computed by WSU-CHARIMA was accomplished in two distinct phases. First, the Columbia River hydraulics were validated by comparing the model-estimated water levels with the measured river stage. The second and final stage of validation was the estimation of water concentrations at river locations where historical measurements were available. Validation was accomplished by computer-modeled routing of the reactor source term estimates for chromium-51 from the reactor locations downstream to the historical river monitoring locations and comparing the computed with the historically monitored results.

A sample comparison of the estimated water concentrations with historical measurements is shown in Figure 3.5. In general, the two data sets agree well. With the exception of the September 1967 data, all estimated monthly average concentrations shown in Figure 3.5 fall within the range of the monthly measurements. This sample is typical of the comparisons between the estimated and measured water concentrations. For some locations and radionuclides, the comparisons are not as close. The agreement between estimated and measured data is further discussed in Walters et al. (1994).

Sediment correction factors were found to be unnecessary (Walters et al. 1994). The validation exercise showed that while some sediment interaction did occur, there was no consistent correlation with season or river discharge. The impact of sediment effects was much less important than the

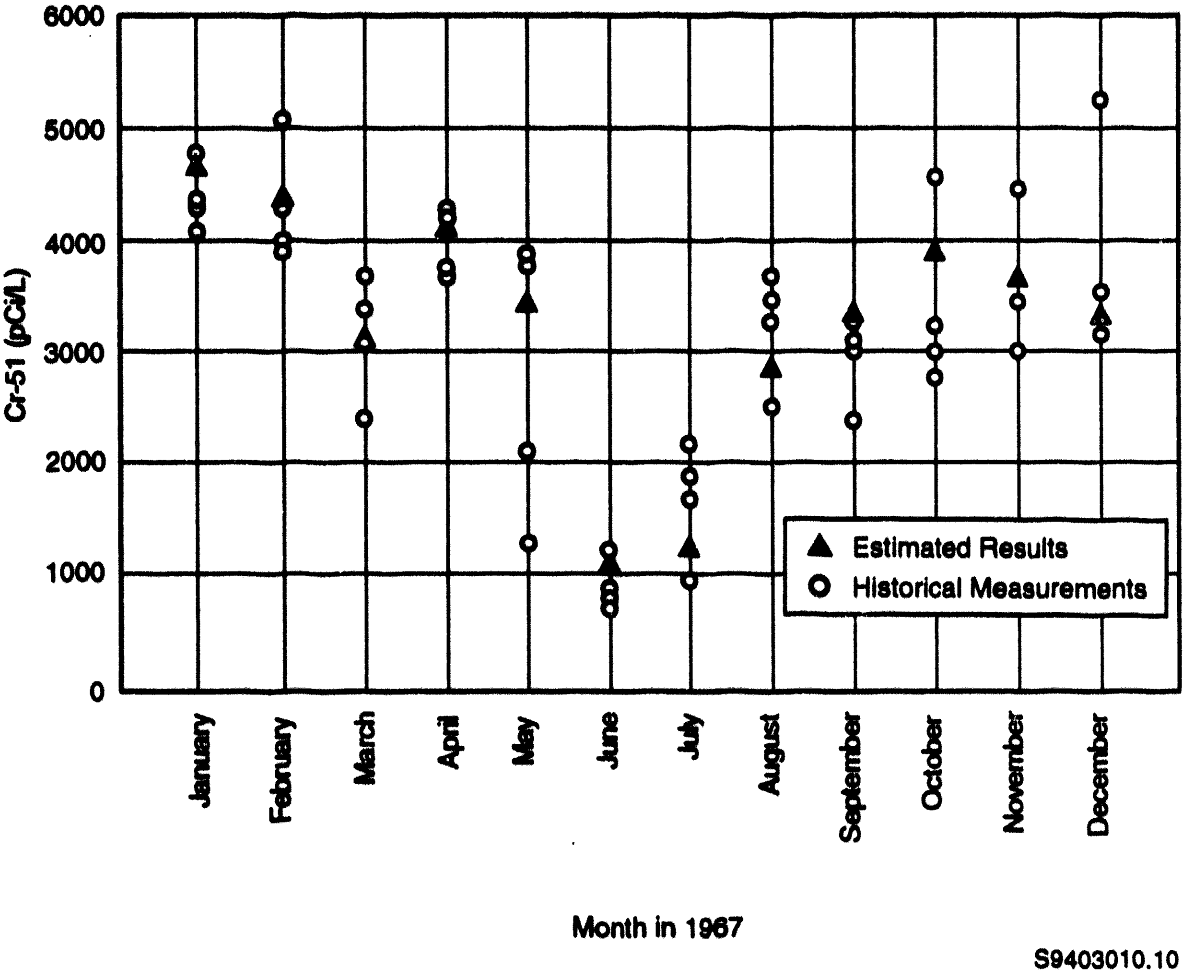


Figure 3.5. Comparison of Estimated versus Measured Radioactivity in Columbia River Water at Richland, Washington (from Walters et al. 1994)

effects of travel time and river discharge. Following validation of the WSU-CHARIMA model and its input data, concentrations for the complete set of radionuclides and time periods at the 12 river locations were developed.

3.2.3 Columbia River Modeling Results

Monthly average concentrations of the five radionuclides (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) for a total of 253 months were estimated by the WSU-CHARIMA computer model (Walters et al. 1994). Modeling started with January 1950 data and ended with January 1971 data. (The last single-pass reactor was shut down in January 1971.) Figure 3.6 shows model-estimated concentrations of the five radionuclides at Richland, Washington, for the period 1956 to 1965. A distinct seasonal cycle, with annual maximum concentrations occurring in the winter, is evident in the data. These maxima resulted from reduced Columbia River flow in the winter. During

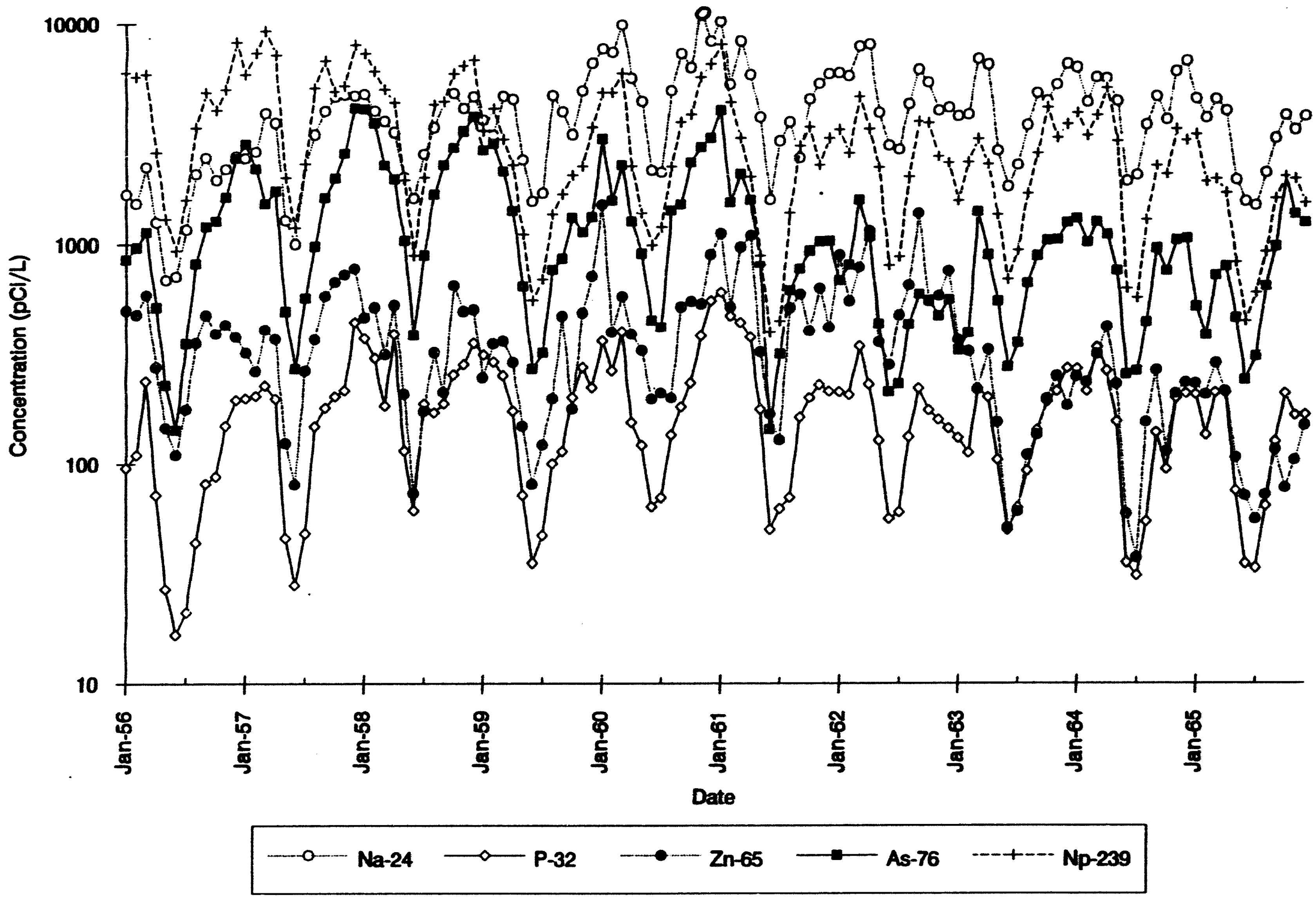


Figure 3.6. Estimated Radionuclide Concentrations in Columbia River Water at Richland, Washington, 1956-1965

late spring and summer, the melting snow in the Cascades and Rocky Mountains increased the river flow, causing increased dilution of Hanford originated radionuclides. During parts of July and August 1966, all Hanford reactors were shut down because of a labor strike. The reduced radionuclide releases during these two months are included in the source term, river transport, and dose modeling.

3.3 Radionuclide Concentrations in Aquatic Organisms

In order to estimate doses to individuals who ingested aquatic organisms (fish, waterfowl, Willapa Bay oysters, and salmon) taken from the Columbia River, the radionuclide concentrations in those organisms must be determined. Several different approaches were used to estimate the concentrations of radionuclides in aquatic organisms. Each approach relied heavily on historical measurements collected by Hanford researchers, other state and federal government agencies, and nongovernment agencies, such as universities. The approaches used to estimate the radionuclide concentrations in fish and waterfowl, Willapa Bay oysters, and salmon are explained below.

3.3.1 Fish and Waterfowl Bioconcentration Factors

The concentration of radioactive material in fish and waterfowl can be related to the radionuclide concentration in the water in which that organism lives and feeds (NCRP 1984). This relationship is a simplistic correlation that accounts for ecosystem interactions between the water and the organism. This simplistic approach was used to develop bioconcentration factors (BCFs) that directly relate the radionuclide concentration in the organism to that in the Columbia River water. A large database of measured radionuclide concentrations in Columbia River fish, waterfowl, and water was assembled and used by HEDR Project staff to develop BCFs.

Historical data from the Columbia River have been used to estimate BCFs specific to the river. As noted in summaries of BCFs in Vanderploeg et al. (1975) and Poston and Klopfer (1988), fish BCFs vary greatly depending on site-specific conditions of a river system. For a given aquatic system, BCFs are generally independent of location and year but dependent upon radionuclide, animal species, and the season of the year.

The development of BCFs for fish resident in the Columbia River is discussed at length in Thiede et al. (1994). That report includes a detailed description of the data used and the resulting BCFs that were used in the dose calculations. All BCFs are for the edible flesh and not the whole fish. BCFs were determined using the following model:

$$BCF = F / W \tag{3.1}$$

where BCF = bioconcentration factor (liter/kilogram)
F = concentration of the radionuclide in fish or waterfowl muscle (picocurie/kilogram)
W = concentration of the radionuclide in water (picocurie/liter).

When historical sample data are lacking, the radionuclide concentration in fish and waterfowl can be approximated using estimated BCFs for the Columbia River and the water concentrations modeled by WSU-CHARIMA (Walters et al. 1994), as follows:

$$F = BCF * W_c \quad (3.2)$$

where F = radionuclide concentration in fish or waterfowl at a given location (picocurie/kilogram)

BCF = bioconcentration factor (liter/kilogram)

W_c = WSU-CHARIMA estimated water concentration of a radionuclide (radionuclide and location specified by F) (picocurie/liter).

3.3.1.1 Fish Bioconcentration Factors

Table 3.1 presents the median BCFs for the five key radionuclides in this study (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) as well as chromium-51. Thiede et al. (1994) present a full description of the statistical uncertainty associated with these BCFs. Table 3.1 presents the BCFs for five radionuclides for three types of Columbia River fish (omnivorous and first- and second-order predators) and with cool and warm seasons. Omnivorous fish include bullhead, catfish, suckers, whitefish, chiselmouth, chub, sturgeon, minnows, and shiners. First-order predators include perch, crappie, punkinseed, and bluegill. Second-order predators include bass, trout, and squawfish. (Salmon and steelhead are treated separately and are discussed in Section 3.3.3.) The cool season for the Columbia River is considered December through May, and the warm season June through November.

3.3.1.2 Waterfowl Bioconcentration Factors

Historical data listing radionuclides in waterfowl were documented as early as 1946 (Parker and Norwood 1946a, 1946b). Hanf et al. (1992) describe the historical documents for waterfowl samples for 1945-1972. These documents show that before 1958, only gross beta was measured. By 1960, individual radionuclides could be measured. In general, zinc-65 and phosphorus-32 were the only radionuclides routinely measured in waterfowl taken from the Columbia River and adjacent areas. These historical measurements provide a basis from which to calculate the Columbia River BCFs for waterfowl (Thiede et al. 1994).

Two general types of ducks were included in this study: diver ducks (which eat small fish and invertebrates) and puddle ducks (which eat near-surface water plants and grain crops). Diver ducks found on the Columbia River include goldeneye, bufflehead, canvasback, merganser, coot, scaup, and ruddyduck. Puddle ducks include mallards, gadwall, pintail, shovelers, widgeon, and woodduck. Geese feed in a manner similar to puddle ducks and were included in this summary because historical data were available. Approximately 72 percent of the 1684 measurements were for puddle ducks, 17 percent for diver ducks, and 11 percent for geese. The waterfowl BCFs used in the dose calculations are listed in Table 3.2. Bioconcentration factors were not calculated for sodium-24, arsenic-76, and neptunium-239 because these radionuclides were typically not detected in waterfowl samples. These BCFs are for all seasons, because no seasonal dependence was found in the historical sampling data. Thiede et al. (1994) present a full description of the uncertainty associated with these BCFs.

Table 3.1. Median Bioconcentration Factors for Columbia River Fish Using Historical Fish Measurements and WSU-CHARIMA Estimated Water Concentrations (from Thiede et al. 1994)

Radionuclide	Fish Type/Season	Median Bioconcentration Factor
sodium-24	omnivorous	80
sodium-24	all predators	2.1
phosphorus-32	omnivorous cool season	420
phosphorus-32	omnivorous warm season	1500
phosphorus-32	all predators cool season	76
phosphorus-32	all predators warm season	980
zinc-65	omnivorous cool season	130
zinc-65	omnivorous warm season	220
zinc-65	1st-order predators cool season	97
zinc-65	1st-order predators warm season	250
zinc-65	2nd-order predators cool season	67
zinc-65	2nd-order predators warm season	110
arsenic-76	all species and seasons	240
neptunium-239	all species and seasons	21
chromium-51	all species and seasons	1.7

Table 3.2. Median Bioconcentration Factors for Columbia River Waterfowl (from Thiede et al. 1994)

Radionuclide	Median Bioconcentration Factor (L/kg)
phosphorus-32	290
zinc-65	44

Figure 3.7 shows zinc-65 concentrations in aquatic organisms. Concentrations of all five key radionuclides were calculated using the estimated water concentration data shown in Figure 3.6 and the BCFs described above.

3.3.2 Willapa Bay Shellfish Data

Zinc-65 and phosphorus-32 concentrations in aquatic organisms near the mouth of the Columbia River were monitored as early as 1959. Walters et al. (1992) give a summary of average radionuclide concentrations at Willapa Bay for 1959-1977. Oysters from Willapa Bay were found to contain measurable amounts of Hanford originated radionuclides (Essig et al. 1973). Hanf et al. (1992) describe documents containing historical information on radionuclides in shellfish (primarily bivalve mollusks). Information from these references was compiled into a database. Thiede et al. (1994) list summary data from this database for phosphorus-32 and zinc-65 for locations such as Willapa Bay, Astoria, Cannon Beach, Coos Bay, Seaside Beach, Tillamook Bay, and Agate Beach. Oysters generally contained higher concentrations of zinc-65 than did other marine organisms (Foster and Wilson 1962).

The total reactor output of zinc-65 by year (Heeb and Bates 1994) was compared, using a linear regression coefficient, to the average zinc-65 concentration in oysters at Willapa Bay. The coefficient was 0.0019 picocurie/gram per curie/year (R^2 = 0.83, calculated without an intercept term), indicating that for each curie of zinc-65 released during a given year, there would be 0.0019 picocurie/gram of zinc-65 in oysters. Using this information, it is possible to approximate the activity of zinc-65 in oysters for years for which there is little or no historical data (1944-1959). Then, the following equation was used to convert reactor production to radioactivity in oysters for any given year:

$$WBO = 0.0019\ C \tag{3.3}$$

where WBO = activity of zinc-65 in Willapa Bay oysters (picocurie/gram)
0.0019 = estimated regression coefficient (picocurie/gram per curie/year)
C = number of curies of zinc-65 released from Hanford production reactors during a given year (curie) (from Heeb and Bates 1994).

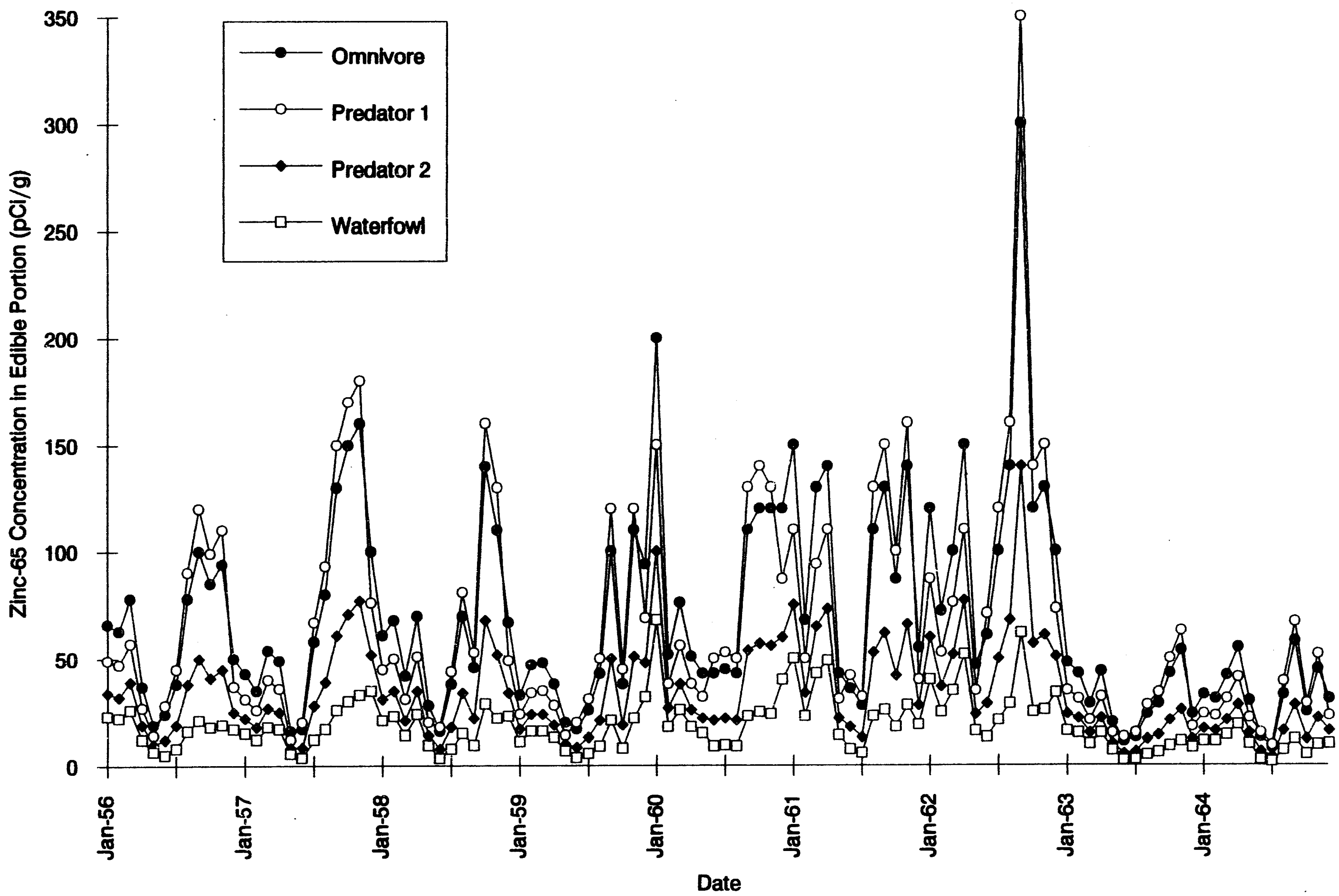


Figure 3.7. Estimated Zinc-65 Concentrations in Aquatic Organisms at Richland, Washington, 1956-1964

3.3.3 Salmon Data

Anadromous species (fish that live part of their lives in freshwater and part in salt water), such as chinook salmon, sockeye salmon, coho salmon, and steelhead trout, travel up the Columbia River to spawn. Walters et al. (1992, Figure 4.5) summarize the time periods when these species are found in the Columbia River. According to Foerster (1968), sockeye, in common with other Pacific salmon species, do not feed once they enter fresh water and head upstream to their natal spawning area. Evidence for this lack of feeding comes from stomach content analysis, decreased fat and protein content, and atrophy of digestive organs. Feeding usually ceases prior to spawning (Brown 1957; Foerster 1968; Meehan 1991), and the fish rely on reserves of fat and protein stored up during their ocean residence to reach their natal spawning area.

Juvenile salmon and steelhead feed during their 3- to 24-month river migration downstream to the ocean (Oregon Department of Fish & Wildlife and Washington Department of Fisheries 1993). However, for the purpose of dose assessment, it is assumed that anadromous species such as salmon and steelhead in the Columbia River took in radionuclides primarily while feeding on organisms in the ocean. These ocean organisms may have accumulated radionuclides from both Columbia River discharge and atmospheric nuclear weapon's test deposition. Accumulation of radionuclides in upstream anadromous species may have depended on the radionuclide accumulation from food sources and accumulation from radionuclide concentrations in the Columbia River. The radionuclide concentration in the fish muscle would then depend on what the fish had accumulated before it moved into the river and on the concentration of radionuclides in the Columbia River water. Data for 47 historical samples of salmon caught in the Columbia River show that 37 samples were at or below the minimum detection limit (0.1 picocurie/gram) for zinc-65. The rest of the samples varied from just above the detection limit to a maximum of 13 picocuries/gram. The median value for zinc-65 was 0.6 picocurie/gram.

The TSP determined that doses from salmon and steelhead should be calculated using two approaches.[a] The first approach would be to use available historical measurements. Using this approach, a default value of 1 picocurie/gram was used for the concentration of zinc-65 in salmon and steelhead flesh for all years (corresponding with the median monitored concentration of 0.6 picocurie/gram, which was rounded to 1 picocurie/gram). The second approach assumed that the salmon spend their entire lives in the Columbia River and accumulate radionuclides as do resident species.

The second approach (treating salmon and steelhead as resident species in the Columbia River) was selected by the TSP because it provided an upper limit for doses from ingestion of salmon and steelhead. This approach was used to estimate the uncertainty in salmon and steelhead doses. The BCF values for resident second-order predators (trout, bass, and squawfish) were used to model all radionuclide concentrations in salmon. If actively eating, salmon would have feeding habits similar to those of second-order predators (i.e., they would feed on smaller fish). This approach yielded zinc-65 concentrations in salmon ranging from about 1 picocurie/gram to 100 picocuries/gram. Figure 3.8 shows the 47 historical measurement points (many points overlap), the default concentration of 1 picocurie/gram specified by the first approach, and the concentrations based on the BCFs of resident

---

(a) Direction given by the Technical Steering Panel (TSP) at the October 7-9, 1993 meeting held in Richland, Washington.

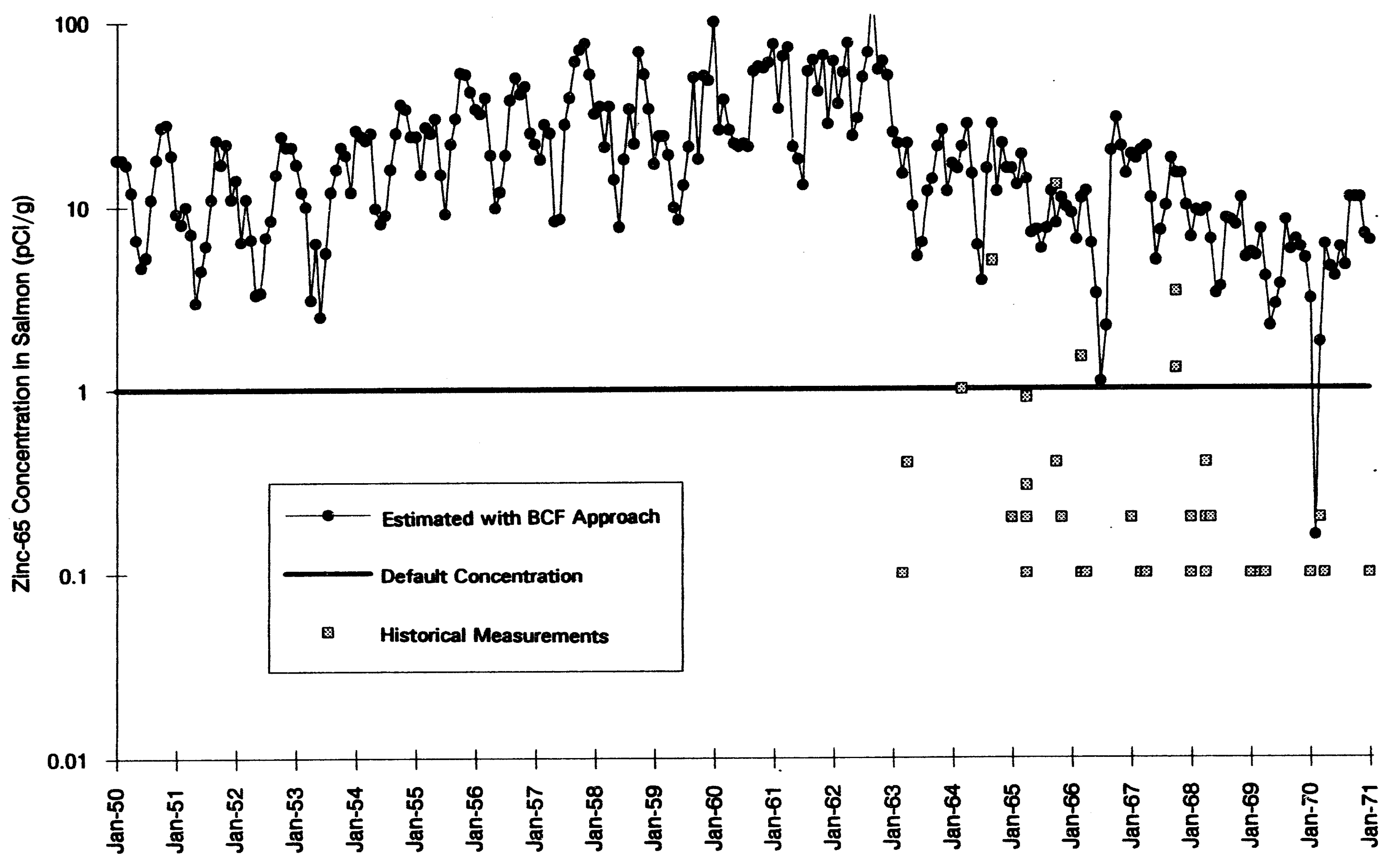


Figure 3.8. Zinc-65 Concentrations in Salmon at Ringold, Washington, 1950-1971

second-order predators (as specified by the second approach). The second approach gives salmon concentrations that are 10 to 100 times larger than the actual monitoring results. Therefore, the second approach should be considered an overestimation of the actual concentrations and doses calculated with this approach are likely to overestimate the actual doses.

3.4 Dose Assessment

Once the source terms and concentrations were estimated, standard dose assessment methods were used to translate the radionuclide concentrations in key environmental media into the radiation dose that could have been received by an individual. The environmental media of concern for the Columbia River pathway include treated and untreated drinking water, resident fish, waterfowl, salmon, and shellfish. Also evaluated were external exposures from swimming, boating, and shoreline activities.

The following subsections introduce the use of the computer code designed to estimate doses to individuals via these environmental media, explain the calculation of doses, and define the categories of individuals assessed for doses from the Columbia River pathway.

3.4.1 Capabilities of the Columbia River Dosimetry Code

The requirements for the computer code used to estimate radiation doses resulting from the Columbia River pathway are documented in Farris (1993) and specify that the code estimate the radiation from a number of pathways and radionuclides. The computer code that was developed, Columbia River Dosimetry (CRD), uses water concentrations of sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239 calculated by the WSU-CHARIMA model (see Section 3.2).

Radionuclide-dependent water treatment factors are used to account for the moderate reduction in radionuclides in drinking water after treatment in a municipal treatment system. An untreated drinking water pathway is also included where no such reduction is assumed.

CRD supports the deterministic estimation of environmental accumulation and dose. This means that the code calculates a single-point estimate of all media concentrations and doses. (A stochastic analysis was performed to investigate the uncertainty and sensitivity of input parameters and calculated doses in the CRD code. The methodology for and results of that analysis are presented in Section 5.0.)

CRD calculates doses for 12 specific river segments (refer to Figure 3.4). The segment names and approximate locations are as follows:

1. Ringold (from below reactor areas to north of Richland)
2. Richland (from north of Richland to above the Yakima River)
3. Kennewick/Pasco (from below the Yakima River to the Snake River)
4. Snake/Walla Walla rivers (from below the Snake River to near McNary Dam)
5. Umatilla/Boardman (from near McNary Dam to near Arlington, Oregon)
6. Arlington (Arlington, Oregon vicinity)

7. John Day Dam/Biggs (from below Arlington, Oregon, to near Biggs, Oregon)
8. Deschutes River (Deschutes River mouth vicinity)
9. The Dalles/Celilo (The Dalles/Celilo vicinity)
10. Klickitat River (Klickitat River mouth vicinity)
11. White Salmon/Cascade Locks (from White Salmon River to Bonneville Dam)
12. Lower River (from below Bonneville Dam to Columbia River mouth)

On the recommendation of the TSP,[a] doses from ingestion of two environmental media with location-dependent concentrations but not directly river-dependent concentrations were also estimated, bringing the number of locations of interest for dose assessment to 14. The two additional doses were those resulting from ingestion of shellfish from Willapa Bay and from salmon and steelhead caught at any location in the Columbia River.

In addition, for each category of individual for whom a radiation dose was estimated, specific parameters relating to exposure are supplied in CRD. Each of the following exposure parameters can be specified by month in the CRD code:

a. river use - swimming (hours/month)
b. river use - boating (includes fishing and shoreline activities) (hours/month)
c. untreated drinking water ingestion (liters/month)
d. treated drinking water ingestion (liters/month)
e. resident fish (omnivore) ingestion (kilograms/month)
f. resident fish (first-order predator) ingestion (kilograms/month)
g. resident fish (second-order predator) ingestion (kilograms/month)
h. waterfowl ingestion (kilograms/month)
i. Willapa Bay shellfish ingestion (kilograms/month)
j. Columbia River anadromous fish (salmon/steelhead) ingestion (kilograms/month).

3.4.2 Equations in the Columbia River Dosimetry Code

The basic equations implemented in the CRD code are shown below. Shown first are equations for radionuclide concentrations in Columbia River water. Then, there are the equations for doses from environmental media. See Snyder et al. (1994) for details about the selection of the parameter values. Doses were calculated using methods described in ICRP (1977). Doses were estimated for each radionuclide, location, and month. As recommended by the TSP,[b] the results include estimations of effective dose equivalent (EDE) as well as estimations of dose equivalent to the red bone marrow (RBM) and to the lower large intestine (LLI). These two critical organs were selected because they are the organs that would have received the highest radiation doses.

(a) Letter (HEDR Project Document No. 07930224), "HEDR Project Locations for Calculation of Radionuclide Concentrations in the Columbia River (14)," from D.E. Walker, Jr. (TSP) to W.A. Bishop (TSP), April 2, 1993.

(b) Letter (HEDR Project Document No. 08910177), "Scoping Documents for Determination of Temporal and Geographical Domains for the HEDR Project," from B. Shleien (TSP) to Distribution, July 26, 1991.

3.4.2.1 CRD Code Equations for Radionuclide Concentrations

The radionuclide concentration in untreated Columbia River water for each location and month is calculated as follows:

$$C_w = C_x P \tag{3.4}$$

where C_w = concentration of radionuclide in Columbia River water at point of human contact (picocurie/liter)
C_x = cross-section average concentration of radionuclide in Columbia River water (picocurie/liter)
P = plume correction factor for each location (unitless).

The plume correction factor accounts for the difference in the shoreline concentration relative to the average concentration across the river. At Ringold, the radionuclide concentrations are greater on the Hanford shore than on the Ringold shore (Walters et al. 1994). The WSU-CHARIMA code calculates the average concentration in the Columbia River at each downstream location. The plume correction factor allows the determination of the actual shoreline concentration using the WSU-CHARIMA calculated values. The plume correction factors used are 0.5, 1.1, and 0.9 for the Ringold, Richland, and Pasco locations, respectively. The derivation of these factors is based on in-stream studies on the Columbia River and are explained in more detail in Walters et al. (1994). At all other locations, the river is assumed to be fully mixed and no plume correction is warranted. The plume correction factor for Ringold is for the east shore, which is accessible to the general population. The Richland and Pasco locations are for the shoreline locations with the maximum estimated concentrations.

The radionuclide concentration in the edible flesh of resident fish and waterfowl for each location and month is calculated in CRD as:

$$C_f = C_x \, BCF \tag{3.5}$$

where C_f = concentration of radionuclide in fish or waterfowl (picocurie/kilogram)
C_x = cross-section average concentration of radionuclide in Columbia River water (picocurie/liter)
BCF = bioconcentration factor for a given species of fish or waterfowl (picocurie/kilogram per picocurie/liter).

The bioconcentration factors are those defined in Section 3.3.1 above.

3.4.2.2 CRD Code Equations for Doses

Ingestion of Water. The monthly dose to each organ from ingestion of treated and untreated water for each location and month is calculated as:

$$D_w = C_w \left[\left(e^{-\lambda\, th_{w1}}\, R_{w1}\, f_w\right) + R_{w2}\right] DF_i \tag{3.6}$$

where D_w = effective dose equivalent or organ dose equivalent from ingestion of all drinking water (millirem/month)
C_w = concentration of radionuclide in Columbia River water at point of human contact (picocuries/liter)
λ = radionuclide-specific radiological decay constant (per day)
th_{w1} = holdup time for treated drinking water (days)
R_{w1} = amount of treated drinking water ingested (liters/month)
f_w = water treatment transmission factor (unitless)
R_{w2} = amount of untreated drinking water ingested (liters/month)
DF_i = dose conversion factor for ingestion (millirem/picocurie).

The ingestion dose conversion factors are from DOE (1988). The drinking water transmission factors have been derived from historical measurements at water treatment facilities in Richland, Kennewick, and Pasco, Washington. The transmission factors account for the radioactivity that passes through the treatment process and is not removed. The transmission factors for the five key radionuclides of interest are listed in Table 3.3. Supporting information for these values is presented in detail in Snyder et al. (1994):

Table 3.3. Transmission Factors for Five Key Radionuclides

Radionuclide	Transmission Factor
sodium-24	0.9
phosphorus-32	0.38
zinc-65	0.39
arsenic-76	0.5
neptunium-239	0.67

Ingestion of Resident Fish and Waterfowl. The monthly dose to each organ from resident fish and waterfowl ingestion for each location and month is calculated in CRD as:

$$D_f = C_f\, R_f\, e^{-\lambda\, th_f}\, DF_i \tag{3.7}$$

where D_f = effective dose equivalent or organ dose equivalent from ingestion of resident fish or waterfowl (millirem/month)
C_f = concentration of radionuclide in fish or waterfowl (picocuries/kilogram)
R_f = amount of fish or waterfowl ingested (kilograms/month)
λ = radiological decay constant (per day)
th_f = holdup time for resident fish or waterfowl (days)
DF_i = dose conversion factor for ingestion (millirem/picocurie).

External Dose. The monthly external dose to each organ for each location and month is calculated as:

$$D_e = C_w \left(\frac{1}{2}E_b + E_{sw}\right) K \, DF_e \tag{3.8}$$

where
D_e = effective dose equivalent or organ dose equivalent from external exposure to radioactive sources (millirem/month)
C_w = concentration of radionuclide in Columbia River water at point of human contact (picocuries/liter)
E_b = time spent boating, fishing, and on shoreline (hours/month)
E_{sw} = time spent swimming (hours/month)
K = unit conversion factor 1/8766 (year/hour)
DF_e = external dose conversion factor (millirem/year per picocuries/liter)

External dose factors were taken from EPA (1988). This model addresses only exposure to radionuclides in the river water, not those deposited along the shoreline. However, evaluation of information presented in the 1965 and 1966 Hanford annual environmental reports (Soldat and Essig 1966, Essig and Soldat 1967) indicated shoreline exposure to be approximately one-third of the river submersion (swimming) exposure. By including shoreline exposure with boating, which is modeled as one-half of the submersion dose, exposure to shoreline-deposited radionuclides is considered to be covered.

Salmon Ingestion. The monthly dose from salmon ingestion is calculated as:

$$D_s = C_s R_s e^{-\lambda th_s} DF_i \tag{3.9}$$

where
D_s = effective dose equivalent or effective organ dose from ingestion of salmon (millirem/month)
C_s = annual average concentration of radionuclide in salmon (picocuries/kilogram)
R_s = amount of salmon ingested (kilograms/month)
λ = radiological decay constant (per day)
th_s = holdup time for salmon (days)
DF_i = dose conversion factor for ingestion (millirem/picocurie).

Oyster Ingestion. The monthly dose from oyster ingestion is calculated in CRD as:

$$D_o = C_o R_o e^{-\lambda th_o} DF_i \tag{3.10}$$

where
D_o = effective dose equivalent or effective organ dose from ingestion of oysters (millirem/month)
C_o = annual average concentration of radionuclide in oysters (picocuries/kilogram)
R_o = amount of oysters ingested (kilograms/month)

λ = radiological decay constant (per day)
th_o = holdup time for oysters (days)
DF_i = dose conversion factor for ingestion (millirem/picocurie).

3.4.3 Representative Individual Definitions

To estimate the dose to individuals who were exposed to the Columbia River in the past, a set of representative (theoretical) individuals has been selected. The characteristics of these individuals are intended to approximate those of selected segments of the general population. The characteristics of the representative individuals do not match any known person. The representative individuals are used to estimate the doses to these selected population segments.

- **Maximum representative individual** - Assumed to have been a significant user of the river. This individual had maximum or near maximum ingestion rates for resident fish and waterfowl and spent time in or on the river.

- **Typical representative individual** - Typical of the average individual residing near the Columbia River. No resident fish were ingested by this type of individual. This corresponds to information provided in Soldat (1968), Beetle (1972), and Endres et al. (1972). Doses for individuals of this second type who did ingest fish can be inferred from the doses calculated for the maximum representative individual.

- **Occupational representative individual** - A worker who is assumed to have been exposed at work. This individual could have been a ferry or barge worker or someone who spent a significant amount of time on the river and who ingested some salmon and shellfish but no resident fish.

Tables 3.4 through 3.6 list characteristics of the representative individuals.

Reference values were defined for each representative individual's usage and intake rates for each pathway. The usage and intake values vary by month. Holdup times (i.e., the times between removal from the river and ingestion) must also be defined for the reference individuals because of the short half-lives of some of the radionuclides evaluated. The assumed holdup times are shown in Table 3.7. Assumptions are based on values used in historic estimates of intake rates in the region as reported in Hanford Site annual environmental reports from 1958 to 1970, which are summarized in Soldat et al. (1986), and on the authors' judgment.

Table 3.4. Characteristics of the Maximum Representative Individual

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion (kg wet)													
Omnivorous fish	3.0	2.0	0.2	0.2	0.0	0.0	0.0	0.2	1.1	2.0	2.0	3.0	13.7
Predator 1 fish	0.3	1.2	2.8	2.8	3.0	3.0	3.0	2.8	2.0	1.2	1.2	0.3	23.6
Predator 2 fish	0	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0.1	0	2.3
Salmon	-	-	-	-	-	-	-	-	2.5	-	-	-	2.5
Shellfish	0.45	-	-	-	-	-	-	-	-	-	-	-	0.45
Waterfowl ingestion (kg wet)	2	2	2	2	2	0	0	0	0	4	4	2	20
Drinking water intake (L)	61	61	61	61	61	61	61	61	61	61	61	61	732
Treated	0	0	0	1	1	1	1	1	1	1	1	0	8
Untreated													
Boating or fishing (hr)	42	42	42	42	42	42	42	42	42	42	42	42	504
Swimming (hr)	0	0	0	5	5	5	5	5	5	5	5	0	40

Table 3.5. Characteristics of the Typical Representative Individual

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion (kg wet)													
Omnivorous fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Predator 1 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Predator 2 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Salmon	-	-	-	-	-	-	-	-	2.0	-	-	-	2.0
Shellfish	0.45	-	-	-	-	-	-	-	-	-	-	-	0.45
Waterfowl ingestion (kg wet)	-	-	-	-	-	-	-	-	-	-	-	-	0
Drinking water intake (L)	37	37	37	37	37	37	37	37	37	37	37	37	444
Treated													0
Untreated													
Boating or fishing (hr)	0	0	0	0	5	5	5	5	5	0	0	0	25
Swimming (hr)	0	0	0	0	0	3	3	3	3	0	0	0	12

Table 3.6. Characteristics of the Occupational Representative Individual

Parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
CRD food ingestion													0
(kg wet)	-	-	-	-	-	-	-	-	-	-	-	-	0
Omnivorous fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Predator 1 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Predator 2 fish	-	-	-	-	-	-	-	-	-	-	-	-	0
Salmon	-	-	-	-	-	-	-	-	-	-	-	-	0
Shellfish													
Waterfowl ingestion (kg wet)	-	-	-	-	-	-	-	-	-	-	-	-	0
Drinking water intake (L)													
Treated	61	61	61	61	61	61	61	61	61	61	61	61	732
Untreated													
Boating or fishing (hr)	240	240	240	240	238	238	235	235	238	240	240	240	2864
Swimming (hr)	0	0	0	0	2	2	5	5	2	0	0	0	16

Table 3.7. Holdup Times for Various Food Types

Food Type	Holdup Time (days)
Resident Fish	
Omnivores (e.g., bullhead, catfish, suckers, whitefish, chiselmouth, chub, sturgeon)	7
First-order predators (e.g., perch, crappie, punkinseed, bluegill)	2
Second-order predators (e.g., bass, trout, squawfish)	2
Salmon	15
Shellfish	7
Waterfowl	7
Treated water	1
Untreated water	0

4.0 Results

Estimates of doses to individuals from reactor releases to the Columbia River for the years 1944-1992 are presented in this section. All dose estimates are prepared using deterministic techniques, which use a single estimate for each input parameter for a model and return a single output estimate result. Such techniques have no built-in allowance for uncertainty. (See Section 5.0 for information on uncertainty in the dose estimates and the sensitivity of the estimated doses to specific input parameter values.)

Results of the estimations of annual doses from 1944-1992 are presented in Section 4.1. Results are given for three dose estimation approaches for three consecutive time periods: screening dose calculations for 1944-1949, detailed dose calculations for January 1950 through January 1971, and dose calculations using data from Hanford annual environmental reports for 1971-1992. These three methods are based on the level of detail required for doses for the three time periods. These dose results are summarized for effective dose equivalent to a maximum representative individual and results are compared to the earlier feasibility study doses found in the *Columbia River Pathway Report* (PNL 1991).

Section 4.2 provides results for the exposure pathways, comparing the parameters contributing the most to doses received by three types of representative individuals at Richland, Washington, and downstream of the Bonneville Dam. Section 4.3 presents the doses estimated for ingestion of salmon and steelhead, and Section 4.4 presents the doses for ingestion of Willapa Bay oysters.

4.1 Annual Doses, 1944-1992

The dose estimation method used for 1944 through 1992 depended on the time considered. Screening calculations were performed for 1944 through 1949, detailed dose calculations were performed for 1950 through January 1971, and Hanford annual reports were consulted for February 1971 through 1992. The screening calculations were performed for a single location (Richland, Washington), the detailed dose calculations were performed for 12 locations, and the doses obtained from annual reports were for single locations between Ringold and Pasco, Washington.

The level of detail in the dose calculations was based on the magnitude of radionuclide releases for the time period. Based on earlier HEDR Columbia River source term and dose calculations (PNL 1991; Napier and Brothers 1992; Walters et al. 1992), the TSP recommended that dose calculations for 1950-1970 be the most detailed.[a] The modeling techniques discussed in Section 3.0 were developed in response to this recommendation. The time period for detailed calculations was expanded to include January 1971 in order to incorporate the last month of single-pass reactor operations. Less rigorous dose assessment techniques were used for the other time periods because radionuclide releases were much lower during those years.

(a) Memo (HEDR Project Document No. 11920015), "Distribution of Recommendations for FY 93 River Work," from P. C. Klingeman (ET Subcommittee Chair) to M. Power and K. CharLee (Washington State Department of Ecology), September 28, 1992.

4.1.1 Radionuclides Contributing to Dose

Key radionuclides for the Columbia River pathway were determined using scoping dose estimates presented in Napier (1993). That report used source term information based on historical measurements that were incomplete for many radionuclides and time periods. However, the report successfully indicated the radionuclides that could be expected to result in the highest radiation doses. Nineteen radionuclides were examined to determine their significance to dose. Napier (1993) recommended that five radionuclides (sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239) be included in future dose calculations. An additional six radionuclides (chromium-51, scandium-46, manganese-56, gallium-72, yttrium-90, and iodine-131) were included in the source term estimates either because they were needed for river transport validation or they were of particular interest to the TSP.

Similar scoping calculations were performed using the source term data provided in Heeb and Bates (1994). The source term presented in Heeb and Bates (1994) is complete for the 11 radionuclides identified as being of interest to the TSP for 1944 though 1971 and represents the most comprehensive source term for Hanford releases to the Columbia River. The scoping calculations were repeated to confirm that the five radionuclides used in the detailed dose calculations are indeed the most important. The revised calculations were performed for a maximum representative individual at Richland, Washington.

Figure 4.1 shows the contribution to the total effective dose equivalent from the 11 radionuclides for 1944-1971. These percentage contributions were determined from the final dose calculations. The top five radionuclides contributed more than 94 percent of the total dose and were used in the detailed dose calculations.

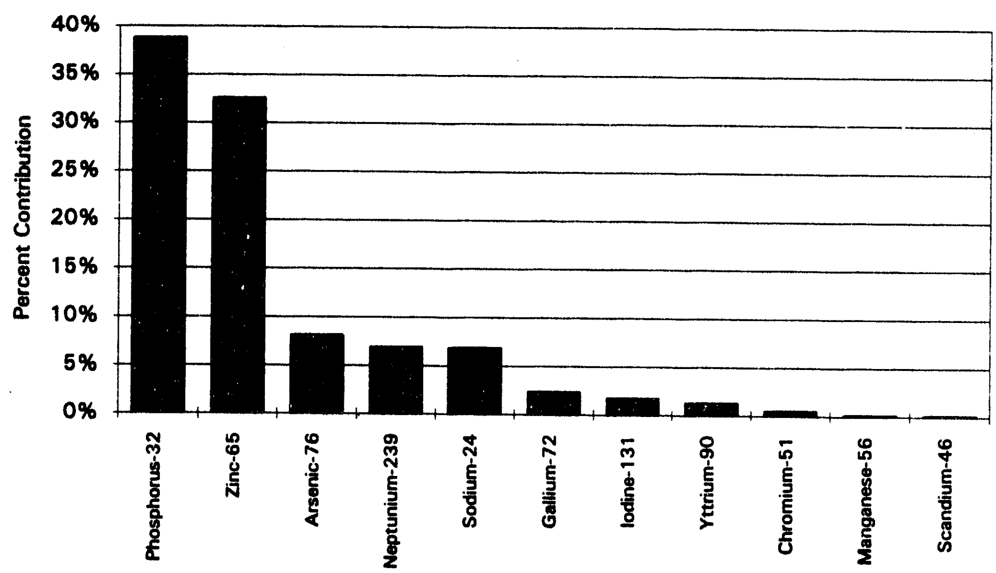


Figure 4.1. Contribution to Total Effective Dose Equivalent for a Maximum Representative Individual at Richland, Washington, 1944-1971

4.1.2 Screening Dose Calculations, 1944-1949

Screening doses to a maximum representative individual at Richland, Washington, were calculated for this report using median values for each radionuclide provided in Heeb and Bates (1994). The WSU-CHARIMA model was not used for these simple calculations. The calculations used a simplified river transport model that assumed an average Columbia River flow rate of 120,000 cubic feet per second and a 19-hour travel time from the reactors to Richland. Assumptions used in these calculations regarding dosimetry and exposure parameters were described in Sections 3.4.2 and 3.4.3.

Table 4.1 presents the doses to a maximum representative individual at Richland, Washington. Doses to the maximum representative individuals at all locations were dominated by the ingestion of fish containing zinc-65 and phosphorus-32. Table 4.1 shows that the effective dose equivalent ranged from 2 millirem/year in 1944 to 25 millirem/year in 1949.

Table 4.1. Doses to a Maximum Representative Individual at Richland, Washington, 1944-1949, from Ingestion of Fish

Year	Effective Dose Equivalent (mrem/yr)	Key Pathway/ Radionuclides
1944	2	fish/Zn-65, P-32
1945	22	fish/Zn-65, P-32
1946	18	fish/Zn-65, P-32
1947	15	fish/Zn-65, P-32
1948	17	fish/Zn-65, P-32
1949	25	fish/Zn-65, P-32

4.1.3 Detailed Dose Calculations, January 1950-January 1971

The doses estimated for this period are the most detailed because they represent the years when an individual using the river would have received the highest dose, particularly the years 1956-1965. The doses were estimated on a monthly basis using detailed estimates of source term, river transport, and human exposure. The dose estimates were computed for each month to maximize the detail included in the dose calculations and to account for any seasonal effects. Radionuclide concentrations in the river, bioconcentration factors, and human characteristics for ingestion and exposure are all highly dependent on the month of the year.

The CRD model (Farris 1993) was used to perform these dose calculations using the monthly source term and river transport estimates documented above (Heeb and Bates 1994; Walters et al. 1994). Doses for this period were calculated for 3 types of representative individuals, 12 specific river locations, 5 radionuclides, and 253 months (January 1950 through January 1971) and include ingestion of Willapa Bay shellfish and Columbia River salmon. Doses were calculated for two specific organs, red bone marrow and lower large intestine, in addition to the effective dose equivalent (whole body dose).

The appendix lists monthly estimates and annual totals of the effective dose equivalent and effective doses to red bone marrow and lower large intestine. These dose estimates are provided for the three representative individual types at 12 locations. Figures 4.2, 4.3, and 4.4 show estimated doses for the three representative individual types at selected locations. Doses at each successive downriver location below Pasco decrease as radioactive decay and river dilution decrease the local radionuclide concentrations. The estimated doses are greatest for the maximum representative individual and lowest for the typical representative individual.

Prior to October 1963, the municipal water supply for the City of Richland, Washington, was drawn from Yakima River water. The Richland municipal water supply after September 1963 was taken from the Columbia River. Figure 4.3 shows the impact of the water source on the doses to the typical representative individual at Richland. Before 1963, the doses to a typical individual at Richland were less than those at Pasco and other locations. After 1963, the doses were highest at Richland. The doses for the maximum and occupational representative individuals do not show the effect because those doses were dominated by exposure pathways other than drinking water.

Within the 1950-1971 time period, the doses for all representative individual types are lowest during the periods 1950-1955 and 1965-1971. The doses peak during the late 1950s and early 1960s, the period of greatest radionuclide releases to the Columbia River (see Section 3.1 and Figure 3.2). The decrease in annual dose in 1959 was a result of slightly lower radionuclide releases and increased river flow during that year. These two factors combined to produce dose estimates that were 30 to 40 percent lower for 1959 than for either 1958 or 1960.

The doses shown in Figures 4.2, 4.3, and 4.4 are the total doses summed over a number of pathways and radionuclides and given as effective dose equivalent. Detailed information on the contributing pathways and radionuclides is presented in Section 4.2. For all monthly dose estimates, it was assumed that salmon contained 1 picocurie/gram of zinc-65. An alternate approach for estimating doses from salmon and steelhead is presented in Section 4.3.

4.1.4 Doses from Hanford Annual Reports, 1971-1992

Annual reports summarizing environmental monitoring and offsite radiation impacts have been prepared by Hanford contractors every year since 1957 (Soldat et al. 1986). These reports are prepared one to two years after the subject year and are available to the public. Each report contains an estimate of the radiation dose to a maximum representative individual for the subject year. Because dose estimation methods are constantly evolving, different assumptions regarding dosimetry, exposure parameters, and modeling were used to arrive at the doses reported for February 1971 through 1992. However, the doses as presented do provide an overview of the overall magnitude and trend of the doses.

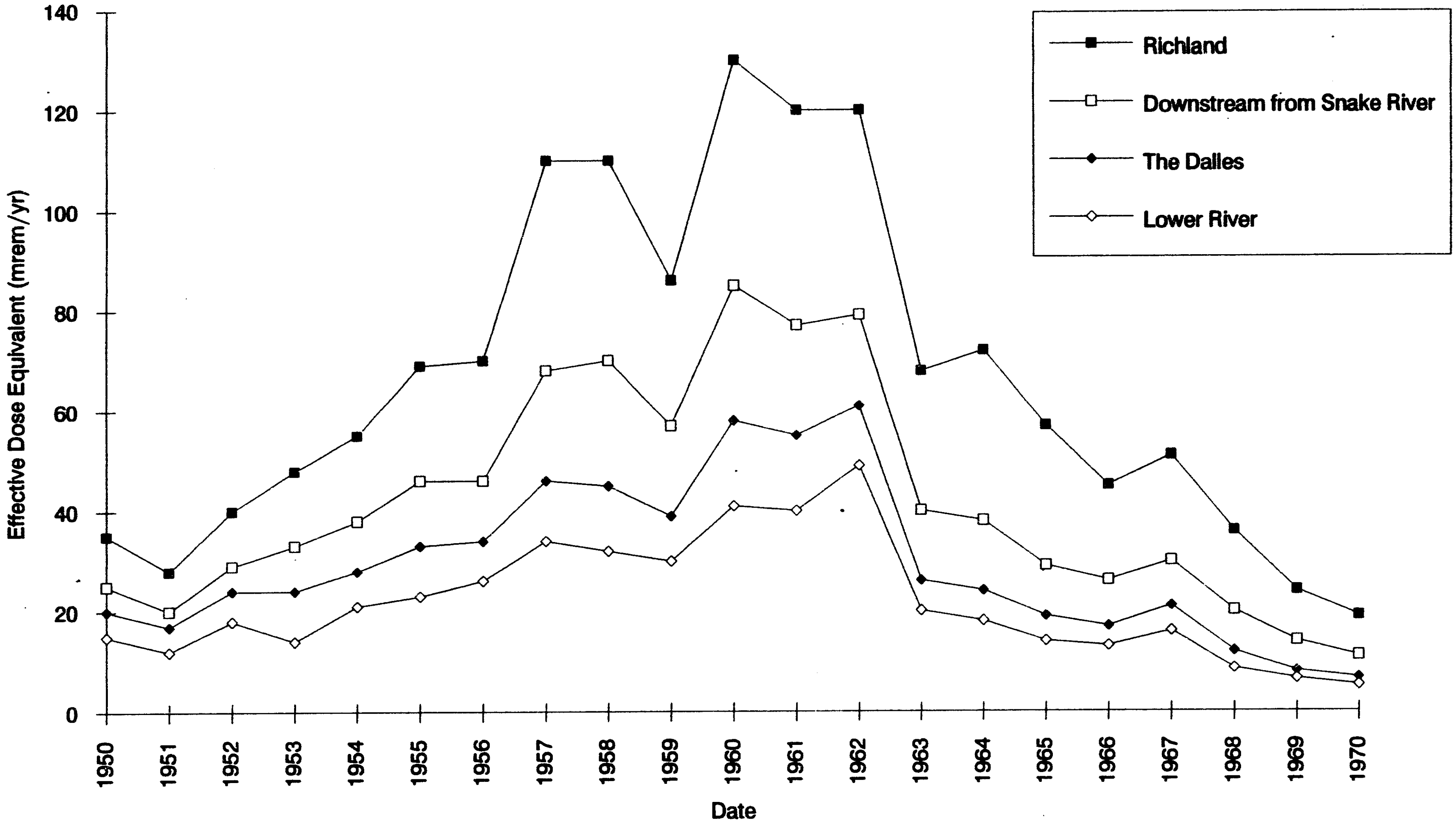


Figure 4.2. Annual Doses to a Maximum Representative Individual at Selected Columbia River Locations, 1950-1970

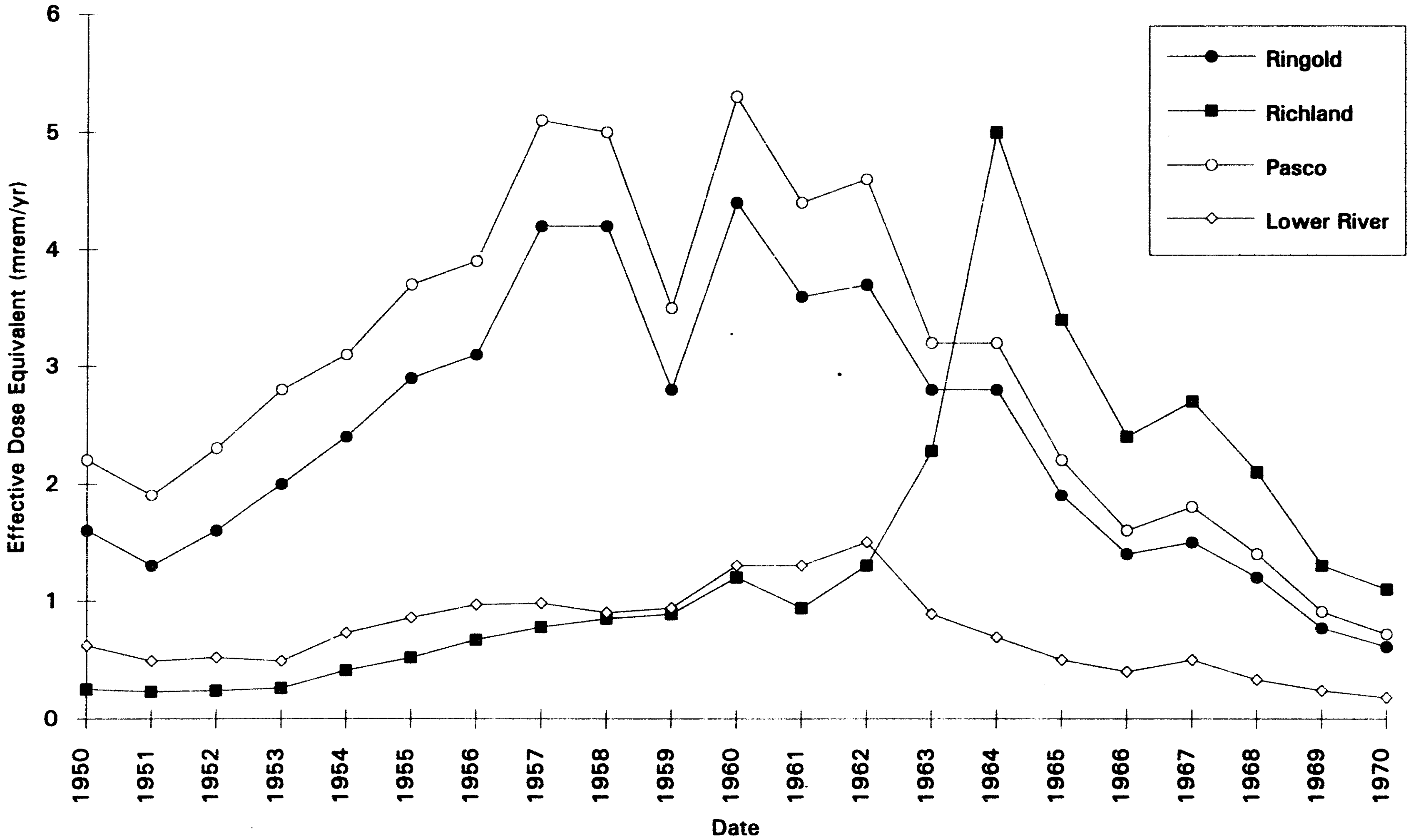


Figure 4.3. Annual Doses to a Typical Representative Individual at Selected Columbia River Locations, 1950-1970

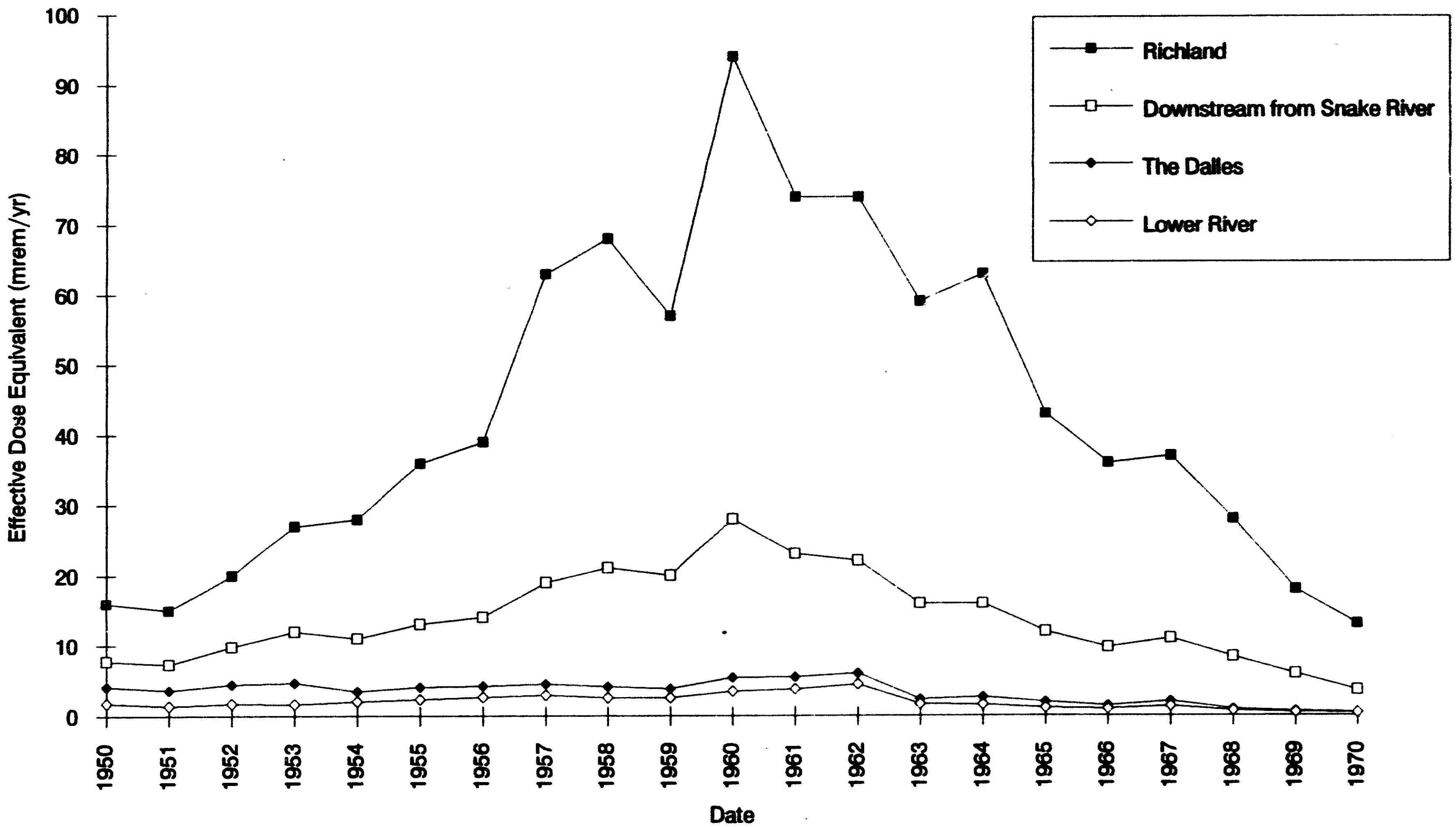


Figure 4.4. Annual Doses to an Occupational Representative Individual at Selected Columbia River Locations, 1950-1970

Doses for 1971 through 1992 are presented in Table 4.2. The most recent year for which a Hanford annual environmental monitoring report is available is 1992. The report for 1993 will be available in late 1994. Dose estimates after 1973 are significantly lower than estimates made for the peak dose years of 1955-1965. Doses dropped significantly after the shutdown of the last single-pass production reactor in January 1971. N Reactor releases during the mid-1980s resulted in doses of a few millirem per year and are included in the doses presented in Table 4.2.

4.1.5 Complete Dose History

Dose results from the three dose estimation approaches (screening calculations, detailed dose calculations, and doses obtained from annual reports) are combined and shown in Figure 4.5. These doses are summarized in Table 4.3. Over 93 percent of the total dose occurred during the 1950-1971 time period. Figure 4.5 shows doses received by a maximum representative individual at Richland, Washington, from 1944-1992. With the exception of Ringold, doses for the maximum individual at other locations would be lower than the doses at Richland, Washington. The annual doses for a typical representative individual are approximately 10 to 40 times lower than those received by a maximum representative individual. Prior to 1963, doses for the typical representative individual at Pasco were higher than at Ringold or Richland. Doses for an occupational representative individual were estimated to be about one-half of those received by a maximum representative individual at Richland.

Doses presented in this report are for three types of representative adults. Doses to children have not been specifically calculated for the three types of representative individuals for all locations and months. Age-dependent doses for children can be inferred from the doses to the typical representative individual adult. For typical representative individuals, both children and adults, the exposure is dominated by consumption of drinking water. The radiation dose from a given intake of any of the five key radionuclides in this study is as much as seven times greater for a child than for an adult (NRPB 1990). However, children consume as little as one-sixth the amount of drinking water and water-based foods as adults (EPA 1989). The net result is that doses for children for any specific year could be a factor of 1.5 to 2 higher than the adult doses for the typical representative individual.

The exposure assumptions for the other two types of representative individuals are not applicable to children. Doses to the occupational representative individual are applicable to an adult who is working on or near the river for 2900 hours/year. The maximum representative individual is estimated to consume large amounts of fish and waterfowl and cannot be considered representative of a child's exposure. Dietary studies done in the late 1960s indicate that most children did not consume game birds or fish from the Columbia River (Soldat and Honstead 1968; Endres et al. 1972). Body burden measurements of 5099 children during 1965-1969 indicated that the average whole body dose to a child in the Richland, Pasco, Kennewick area was approximately 1 millirem/year.

4.1.6 Comparison to Feasibility Study Dose Estimates

The scope of the feasibility study (PNL 1991) included dose calculations for 1964-1966 and locations from the areas of the reactors to McNary Dam. Figure 4.6 shows a comparison of median doses presented in the feasibility study *Columbia River Pathway Report* (PNL 1991) with doses estimated for this report. Doses are shown for maximum and typical representative individuals

Table 4.2. Hanford Annual Report Doses, 1971-1992

Year	Maximum Individual Total Body or Effective Dose Equivalent (mrem)	Reference
1971	3[a]	Soldat, Price, and McCormack. 1986. PNL-5795
1972	2[a]	Bramson and Corley. 1973. BNWL-1727.
1973	2	Soldat, Price, and McCormack. 1986. PNL-5795
1974	0.03	Fix. 1975. BNWL-1910
1975	0.012	Spear, Fix, and Blumer. 1976. BNWL-1979
1976	0.04	Fix, Blumer, Hoenes, and Bramson. 1977. BNWL-2142
1977	0.2	Houston and Blumer. 1978. PNL-2614
1978	0.03	Houston and Blumer. 1979. PNL-2932
1979	<0.09	Houston and Blumer. 1980. PNL-3283
1980	<0.1[a]	Sula and Blumer. 1981. PNL-3728
1981	0.4[b]	Sula, McCormack, Dirkes, Price, and Eddy. 1982. PNL-4211
1982	0.1[b]	Sula, Carlile, Price, and McCormack. 1983. PNL-4657
1983	0.01	Soldat. 1989. PNL-7135
1984	0.057	Soldat. 1989. PNL-7135
1985	0.07	Soldat. 1989. PNL-7135
1986	0.05	Pacific Northwest Laboratory. 1987. PNL-6120
1987	0.03	Jaquish and Mitchell. 1988. PNL-6464
1988	0.02	Jaquish and Bryce. 1989. PNL-6825
1989	0.039	Jaquish and Bryce. 1990. PNL-7346
1990	0.016	Woodruff and Hanf. 1991. PNL-7930
1991	0.009	Woodruff and Hanf. 1992. PNL-8148
1992	0.02	Woodruff and Hanf. 1993. PNL-8682

(a) Annual report presents doses for air and river pathways combined, and it is not possible to separate doses by pathway. Doses presented here are the sum of air and river pathways and are an overestimate of the Columbia River dose.

(b) Annual report presents doses from consumption of foods containing radioactivity released via the air and river pathways combined. It is not possible to separate doses by source.

Table 4.3. Estimated Effective Dose Equivalent to a Maximum Representative Individual at Richland, Washington

Period	Estimated Effective Dose Equivalent (mrem)
1944-1949	99
1950-1971	1400
1971-1992	8

exposed at Richland and Pasco, Washington. Although some differences exist between the two dose assessments, they agree within a factor of 2. The methods used in the two dose assessments were similar, but slightly different model inputs were used. Both the feasibility study and the dose calculations performed for this report show slightly lower doses at Pasco when compared to Richland. The estimated Columbia River concentrations used in these two dose assessments were in very close agreement. The variation in the doses is a result of environmental accumulation and human exposure parameter differences between the feasibility study and this study.

For the maximum representative individual, the resident fish ingestion used in the feasibility study was approximately 20 kilograms/year, while a 40-kilograms/year ingestion rate was used in this study. This factor of 2 accounts for nearly all of the difference between the doses from the two studies. Differences in bioconcentration factors for resident fish exist but do not result in large changes in the estimated doses. For the typical representative individual, the difference can only be explained by the stochastic approach used in the feasibility study.

In the feasibility study, a step-by-step (modular) calculational structure was used. Calculations were performed in sequence (modules), and the result of each module was stored in an intermediate histogram. This structure was intended to simplify the computational process, allow storage of intermediate calculations for later analysis, and guide collection of data by providing an understandable structure for using the data.

To a large extent, the feasibility study code achieved the specified goals. However, the use of histograms to store output from each module of the code resulted in a loss of correlation among code inputs and outputs. Later modules in the sequence independently sampled the intermediate histograms, choosing an input value from among a pool of possible input values. In general, small values of certain parameters should occur concurrently with relatively small values of other parameters, and large values should occur concurrently with other relatively large values. For example, low concentrations of radionuclides in river water would probably occur concurrently with low concentrations of radionuclides in fish and drinking water. However, with independent sampling of intermediate results (such as occurred when modules sampled intermediate histograms), large radionuclide concentrations in river water might have been coupled with low radionuclide concentrations in fish and drinking water.

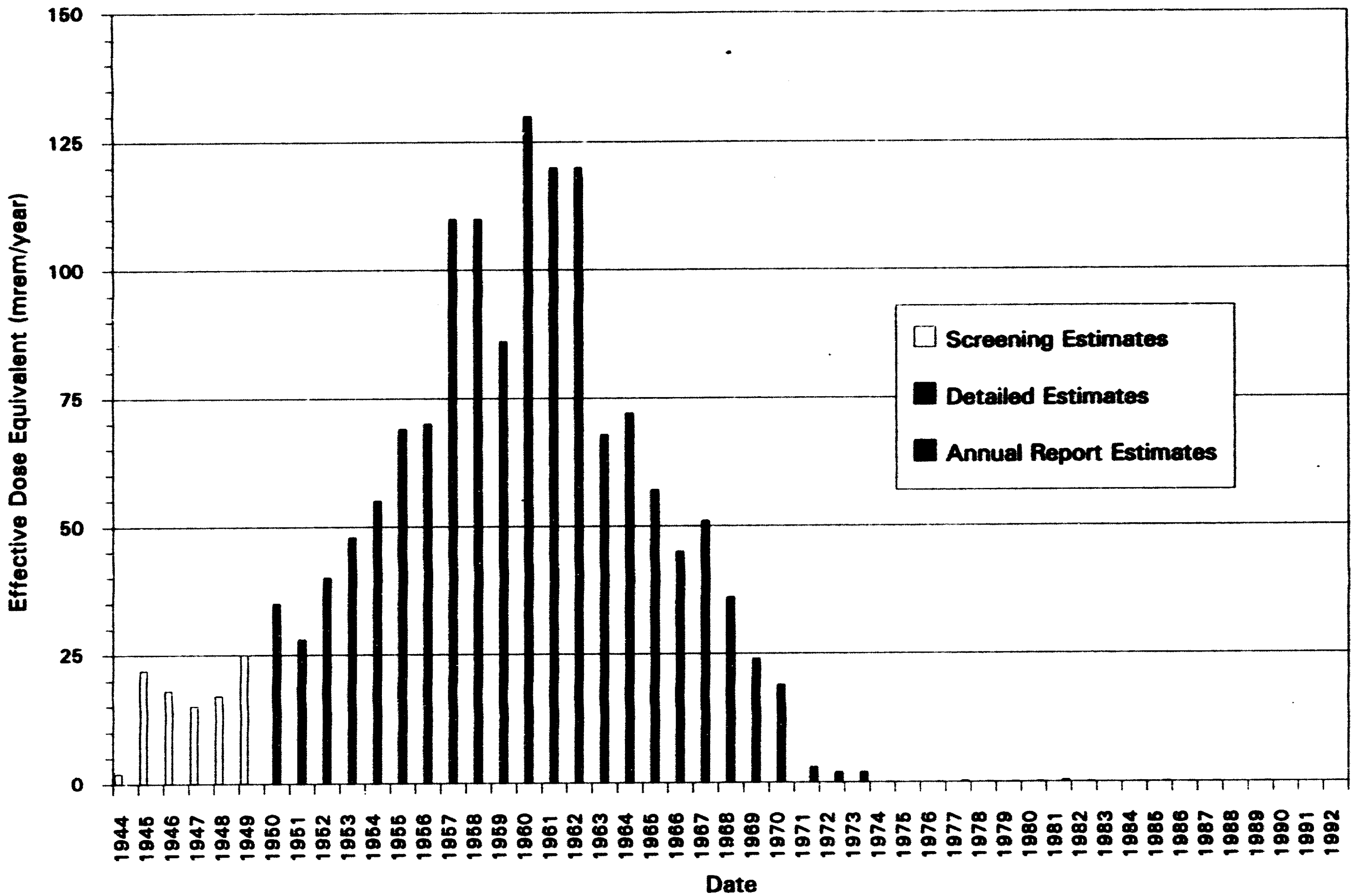


Figure 4.5. Dose History for a Maximum Representative Individual at Richland, Washington, 1944-1992

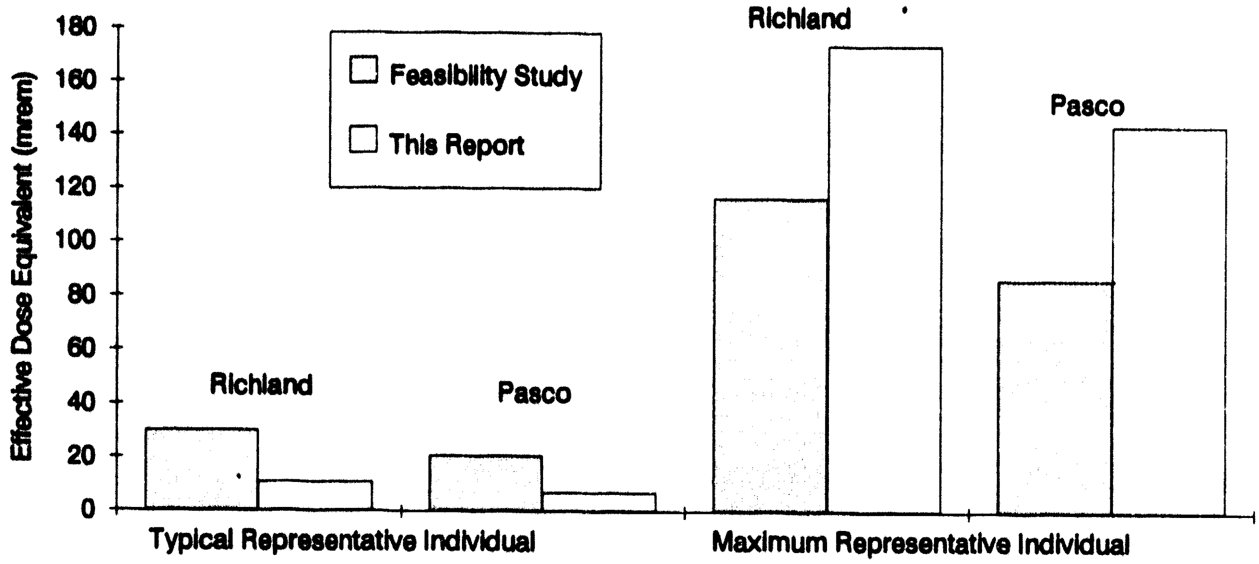


Figure 4.6. Comparison to Feasibility Study Doses, 1964-1966

This loss of correlation between code inputs and outputs resulted in biased dose estimates. The net result was a general overestimation of the mean and median doses for those modes of exposure that were handled by the code as several modules that sampled previous output values. An example of one such exposure pathway that was overestimated by the feasibility study approach is the drinking water pathway. The drinking water pathway included contributions from many different radionuclides. These radionuclides' contribution to the full dose depended on many factors, including source term releases from the reactors, cleanup due to water treatment, and radioactive decay during holdup. The deterministic and stochastic calculations performed in support of this report were conducted so as to preserve the input and output correlations.

4.2 Key Exposure Pathways and Radionuclides

Dose estimate calculations for the three types of representative individuals include doses contributed by the following exposure pathways:

- drinking water ingestion
- resident fish ingestion
- shellfish ingestion
- waterfowl ingestion
- salmon ingestion
- external exposure (swimming, boating, and shoreline).

The calculations include contributions to dose from the five principal radionuclides studied for this report: sodium-24, phosphorus-32, zinc-65, arsenic-76, and neptunium-239. Table 4.4 shows the contributing pathways and radionuclides for the three representative individual types at two

Table 4.4. Pathways and Radionuclides Contributing to Dose, 1956-1965

Typical Representative Individual at Pasco

Nuclide	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	6.3	21.3%	5.9	2.5%	6.6	16.3%	2.6	93.4%	4	12.0%	0	0.0%	0	0.0%	0	0.0%
P-32	7.3	24.4%	6.5	2.8%	1.9	4.6%	0	0.0%	1.9	5.6%	0	0.0%	0	0.0%	0	0.0%
Zn-65	15	49.5%	16	6.9%	12	30.1%	0.042	1.5%	7.8	23.5%	0	0.0%	0.27	100.0%	4	100.0%
As-76	0.46	1.6%	41	17.3%	4.5	11.2%	0.062	2.3%	4.5	13.4%	0	0.0%	0	0.0%	0	0.0%
Np-239	0.95	3.2%	170	70.6%	15	37.8%	0.078	2.8%	15	45.5%	0	0.0%	0	0.0%	0	0.0%
Total Dose	30		240		40		2.7		33		0		0.27		4	
% of Total EDE							6.8%		82.6%		0.0%		0.7%		9.9%	

Typical Representative Individual at Lower River (Bonneville)

Nuclide	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	0.016	0.1%	0.014	0.1%	0.017	0.2%	0.011	22.1%	0.0061	0.1%	0	0.0%	0	0.0%	0	0.0%
P-32	2.4	18.7%	2.2	10.3%	0.62	6.3%	0	0.0%	0.62	11.0%	0	0.0%	0	0.0%	0	0.0%
Zn-65	10	80.8%	12	54.9%	8.6	86.7%	0.029	61.4%	4.3	76.9%	0	0.0%	0.27	100.0%	4	100.0%
As-76	0.0036	0.0%	0.26	1.2%	0.03	0.3%	0.0011	2.4%	0.028	0.5%	0	0.0%	0	0.0%	0	0.0%
Np-239	0.043	0.03%	7.1	33.5%	0.65	6.6%	0.0067	14.0%	0.65	11.4%	0	0.0%	0	0.0%	0	0.0%
Total Dose	13		21		9.9		0.048		5.6		0		0.27		4	
% of Total EDE							0.5%		56.7%		0.0%		2.7%		40.1%	

Table 4.4. (contd)

Maximum Representative Individual at Pasco

Nuclide	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	40	2.3%	37	1.3%	44	5.0%	37	91.7%	6.8	12.2%	0.18	0.0%	0	0.0	0	0.0%
P-32	1200	69.6%	1100	38.1%	310	35.7%	0	0.0%	3.1	5.6%	310	39.9%	0	0.0	0	0.0%
Zn-65	480	27.4%	530	18.7%	390	45.1%	0.69	1.7%	13	23.5%	380	48.7%	0.34	100.0%	4	100.0%
As-76	7.7	0.4%	660	23.1%	73	8.4%	1.2	3.0%	7.6	13.5%	64	8.4%	0	0.0	0	0.0%
Np-239	3.9	0.2%	540	18.8%	50	5.7%	1.4	3.6%	25	45.2%	23	3.0%	0	0.0	0	0.0%
Total Dose	1700		2900		870		40		56		770		0.34		4	
% of Total EDE							4.6%		6.4%		88.5%		0.0%		0.5%	

Maximum Representative Individual at Lower River (Bonneville)

Nuclide	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	0.066	0.0%	0.061	0.0%	0.072	0.0%	0.061	11.5%	0.011	0.1%	0.0004	0.0%	0	0.0%	0	0.0%
P-32	370	60.1%	340	52.2%	96	31.6%	0	0.0%	1.1	11.1%	95	32.8%	0	0.0%	0	0.0%
Zn-65	250	39.9%	280	43.0%	300	67.4	0.39	74.7%	7.4	76.9%	190	66.6%	0.34	100.0%	4	100.0%
As-76	0.068	0.0%	6.1	0.9%	0.67	0.2%	0.0083	1.5%	0.049	0.5%	0.62	0.2%	0	0.0%	0	0.0%
Np-239	0.18	0.0%	25	3.8%	2.3	0.8%	0.064	12.2%	1.1	11.4%	1.1	0.4%	0	0.0%	0	0.0%
Total Dose	620		650		300		0.53		9.6		290		0.34		0	
% of Total EDE							0.2%		3.1%		95.3%		0.1%		1.3%	

Table 4.4. (contd)

Occupational Representative Individual at Pasco

	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
Nuclide	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	190	67.2%	180	16.4%	210	60.4%	190	91.6%	22	15.7%	0	0.0%	0	0.0%	0	0.0%
P-32	33	11.6%	30	2.8%	8.5	2.5%	0	0.0%	8.5	6.0%	0	0.0%	0	0.0%	0	0.0%
Zn-65	43	15.3%	48	4.5%	37	10.7%	3.5	1.7%	33	23.4%	0	0.0%	0	0.0%	0	0.0%
As-76	8.1	2.9%	260	24.2%	34	9.8%	6.2	3.1%	28	19.5%	0	0.0%	0	0.0%	0	0.0%
Np-239	8.5	3.0%	560	52.1%	57	16.7%	7.4	3.6%	50	35.3%	0	0.0%	0	0.0%	0	0.0%
Total Dose	280		1100		340		200		140		0		0		0	
% of Total EDE							58.9%		41.1%		0.0%		0.0%		0.0%	

Occupational Representative Individual at Lower River (Bonneville)

	Dose Equivalent by Organ (mrem)						Dose Equivalent by Pathway (EDE mrem)									
Nuclide	RBM		LLI		EDE		External		Drinking Water		Resident Fish and Waterfowl		Salmon		Shellfish	
Na-24	0.3	0.8%	0.27	0.4%	0.32	1.2%	0.29	11.1%	0.034	0.1%	0	0.0%	0	0.0%	0	0.0%
P-32	11	30.8%	9.9	16.0%	2.8	10.8%	0	0.0%	2.8	12.0%	0	0.0%	0	0.0%	0	0.0%
Zn-65	24	67.2%	27	42.7%	20	77.7%	2	75.2%	18	78.0%	0	0.0%	0	0.0%	0	0.0%
As-76	0.052	0.1%	1.6	2.6%	0.22	0.8%	0.04	1.5%	0.18	0.7%	0	0.0%	0	0.0%	0	0.0%
Np-239	0.36	1.0%	24	38.2%	2.4	9.4%	0.32	12.2%	2.1	9.0%	0	0.0%	0	0.0%	0	0.0%
Total Dose	36		62		26		2.6		24		0		0		0	
% of Total EDE							9.9%		90.1%		0.0%		0.0%		0.0%	

locations: Pasco, Washington, and the lower river below Bonneville Dam. The 1956-1965 time period is presented because it is the period of highest dose for all locations and all representative individual types. As discussed in Section 3.3.3, salmon doses were calculated assuming 1 picocurie/gram of zinc-65 in all salmon.

The pathways contributing to effective dose equivalents at Pasco, Washington, varied depending on the representative individual types:

- For the maximum representative individual, the largest contribution to effective dose equivalent came from the ingestion of resident fish containing zinc-65 and phosphorus-32.
- For the typical representative individual, the largest contribution to effective dose equivalent came from the ingestion of treated drinking water containing neptunium-239, zinc-65, arsenic-76, and sodium-24, in that order.
- For the occupational representative individual, the largest contribution to effective dose equivalent came from external exposure to sodium-24. However, the dose to occupational representative individuals at locations downriver from Richland came from the ingestion of untreated drinking water containing zinc-65.

Similar pathways dominated the doses calculated for corresponding representative individual types located downstream from Pasco:

- For maximum representative individuals, contributions from fish ingestion dominated the dose.
- For both typical and occupational representative individuals, contributions from drinking water dominated the dose.

The ingestion of shellfish from Willapa Bay accounted for 40 percent of the effective dose to a typical representative individual below the Bonneville Dam. However, the 10-years total effective dose equivalent for such an individual was only approximately 10 millirem (1 millirem/year).

Different radionuclides dominated the effective dose equivalent at Pasco and the Columbia River downstream of Bonneville Dam. Doses estimated for Pasco show a higher contribution from sodium-24 and arsenic-76 than those estimated for downriver locations. This was because of the short half-lives of sodium-24 and arsenic-76 (approximately one day or less for each). Radioactive decay resulted in lower concentrations of these two radionuclides in the river downstream of Pasco. Zinc-65 and phosphorus-32 contribute the most to doses at downstream locations.

4.3 Doses from Ingestion of Salmon and Steelhead

The TSP determined that not enough historical measurements exist on radionuclide concentrations in Columbia River salmon and steelhead to unequivocally determine doses resulting from ingestion of these fish over the 1944-1971 time period. Therefore, doses have been calculated using the two approaches described in Section 3.3.3. The first approach relies on the actual historical measurements collected in the 1960s through 1970, and the second approach assumes that salmon and steelhead accumulate radioactivity to the level of resident fish.[a]

The second approach was selected by the TSP because it provided an upper limit for doses from ingestion of salmon and steelhead. This second approach yields zinc-65 concentrations in salmon ranging from about 1 picocurie/gram to 100 picocuries/gram, whereas the historical measurements indicate concentrations ranging from the limit of detection (0.1 picocurie/gram) to a maximum of 13 picocuries/gram. This second approach can be considered a conservative method that likely overestimates the actual doses.

Figure 4.7 and Table 4.5 show the effective dose equivalents resulting from salmon or steelhead ingestion calculated using the first and second approaches, respectively. To estimate dose from Figure 4.7, first determine the applicable ingestion rate on the horizontal axis, then move vertically to the line that represents the organ of interest and read the dose from the vertical axis. For example, the dose equivalent to the red bone marrow from ingestion of 150 kilograms/year (330 pounds/year) would have been about 2.5 millirem/year.

The doses shown in Figure 4.7 were derived from historical measurements calculated using the assumption that the salmon or steelhead contained zinc-65 at 1 picocurie/gram. The 1 picocurie/gram concentration was assumed to be true at every location for the entire period (see Section 3.3.3). The effective dose equivalent was less than 3.5 millirem/year for an ingestion of up to 550 pounds of fresh salmon per year. The doses were calculated with the assumption that all fish were ingested fresh. If the fish were dried and then stored for several months, the doses would have been lower by about 5 percent per month.

To estimate dose from Table 4.5, first determine the applicable ingestion rate from the upper portion of the table. Then, move vertically down to the year of interest and read the dose from that row. For example, the effective dose equivalent from the ingestion of 100 kilograms (220 pounds) of salmon or steelhead in 1961 would be approximately 190 millirem/year. The doses shown in Table 4.5 were calculated using the assumption that salmon and steelhead accumulated radionuclides in a manner similar to that of resident fish. Because this approach is location- and time-dependent, Table 4.5 shows the dose at a specific location (Ringold) for all years (1950-1970). The table shows that the largest doses from this pathway occurred in 1958 and could have been as high as 630 millirem/year from the ingestion of over 250 kilograms (550 pounds) of salmon or steelhead.

Figure 4.8 shows the doses that individuals may have received from ingestion of fish from other locations. The doses presented in this figure are based on the conservative (second) approach and are likely to be overestimations by a factor of 10 to 100. Doses are shown for several locations for the years 1950 through 1970. These doses were estimated using the assumption that salmon and steelhead accumulate radionuclides in a manner similar to that of resident fish. Doses were highest at Ringold and lowest in the lower river where they were approximately 20 to 30 percent of those at Ringold. All doses were estimated assuming an ingestion rate of 220 pounds of salmon/steelhead per year. Doses for other ingestion rates can be calculated by multiplying the dose shown in the figure

---

(a) Direction given by the Technical Steering Panel (TSP) at the October 7-9, 1993 meeting held in Richland, Washington.

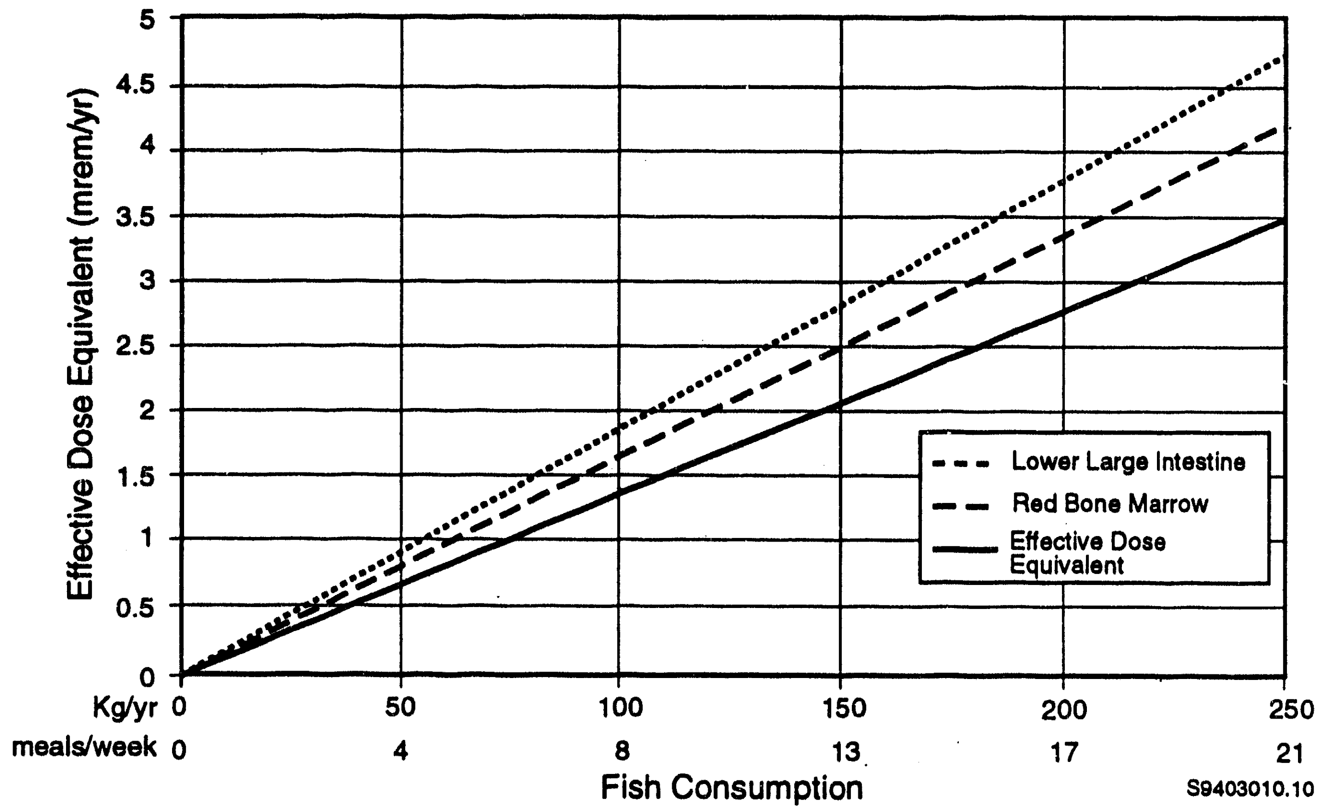


Figure 4.7. Dose from Consumption of Salmon or Steelhead with 1 Picocurie of Zinc-65 per Gram

by the factor of the actual amount ingested divided by 220, as shown in the following example. The dose resulting from ingestion of 100 pounds/year of salmon/steelhead in 1958 would be

$$250 \text{ mrem/yr} * \frac{100 \text{ lb/yr}}{220 \text{ lb/yr}} = 114 \text{ mrem/yr} \tag{4.1}$$

The doses shown in Figure 4.8 can be considered representative of doses from salmon ingestion in tributaries of the Columbia River using the assumption that salmon and steelhead accumulate radionuclides in a manner similar to that of resident fish. A conservative example is where salmon that migrate to the upper reaches of the Snake River are assumed to have given the same dose as those at the mouth of the Snake River (shown by the second line from the top in Figure 4.8). The doses from ingestion of salmon from other tributaries can be determined using the dose for the location on Figure 4.8 nearest the tributary confluence. Salmon caught above Ringold would not have concentrations of radionuclides higher than at Ringold.

Table 4.5. Annual Dose from Consumption of Salmon or Steelhead at Ringold[(a)]

Units	Consumption Rate					
kg/yr	10	50	100	150	200	250
lb/yr	22	110	220	330	440	550
lb/month	2	9	18	28	37	46
meals/wk[(b)]	1	4	8	13	17	21
Year	**Effective Dose Equivalent (mrem/yr)**					
1950	7	35	70	110	140	180
1951	6	32	63	95	130	160
1952	10	50	100	150	200	250
1953	10	50	100	150	200	250
1954	11	55	110	170	220	280
1955	17	85	170	260	340	430
1956	13	65	130	200	260	330
1957	23	120	230	350	460	580
1958	25	130	250	380	500	630
1959	15	75	150	230	300	380
1960	23	120	230	350	460	580
1961	19	95	190	290	380	480
1962	23	120	230	350	460	580
1963	14	70	140	210	280	350
1964	12	60	120	180	240	300
1965	14	70	140	210	280	350
1966	11	55	110	170	220	280
1967	11	55	110	170	220	280
1968	7	36	72	110	140	180
1969	5	26	51	77	100	130
1970	5	26	51	77	100	130

(a) Salmon and steelhead are assumed to accumulate radioactivity in the manner of resident fish.

(b) One meal is 230 grams (one-half pound).

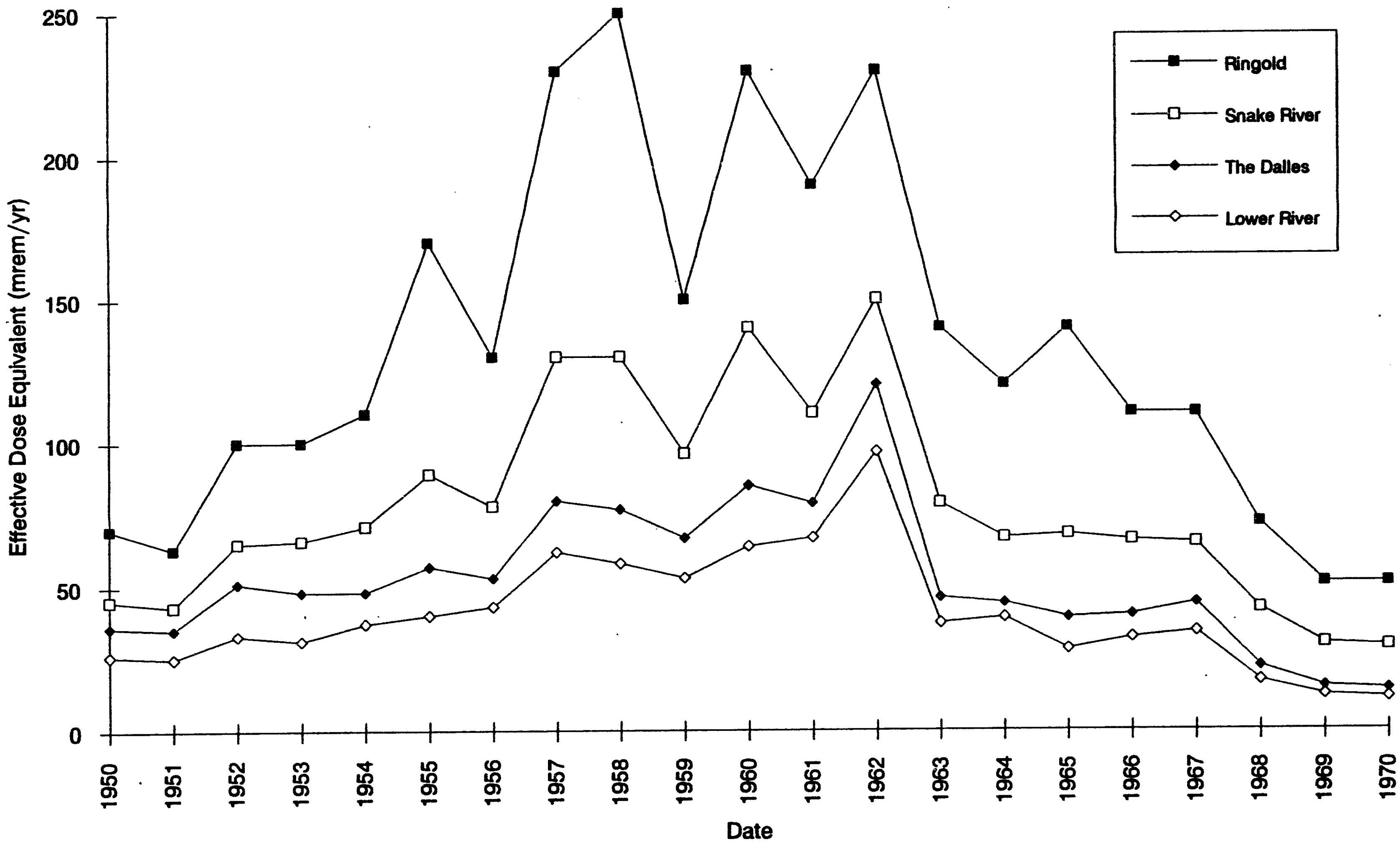


Figure 4.8. Dose from Consumption of 100 Kilograms per Year of Salmon or Steelhead at Selected Locations, 1950-1970

4.4 Dose from Ingestion of Shellfish

The doses from ingestion of oysters from Willapa Bay on the coast of Washington State are shown in Table 4.6. The methods used to estimate the concentrations of zinc-65 in Willapa Bay oysters are described in Section 3.3.2. This table is read in the same way as Table 4.5. For example, the effective dose equivalent from the ingestion of 10 kilograms (22 pounds) of oysters in 1954 would be approximately 6 millirem/year. The largest dose occurred in 1962 and could have been as high as 26 millirem/year from the ingestion of 20 kilograms (44 pounds) of fresh oysters.

Table 4.6. Annual Dose from Consumption of Willapa Bay Oysters

Units	Consumption Rate			
kg/yr	5	10	15	20
lb/yr	11	22	33	44
oz/wk	3	7	10	14
Year	**Effective Dose Equivalent (mrem/yr)**			
1950	2	4	6	8
1951	1	3	4	6
1952	1	2	4	5
1953	1	2	3	5
1954	3	6	9	12
1955	4	7	11	14
1956	4	8	13	17
1957	4	7	11	15
1958	4	7	11	14
1959	4	9	13	17
1960	6	11	17	23
1961	5	10	15	20
1962	6	13	19	26
1963	6	12	18	24
1964	4	7	11	15
1965	3	5	8	10
1966	2	4	6	8
1967	2	4	6	8
1968	2	3	5	7
1969	1	3	4	5
1970	1	2	3	3

5.0 Model Reliability

The Columbia River pathway calculational models were analyzed for their reliability in estimating doses received by representative individuals. In addition to extensive testing, the analyses included uncertainty and sensitivity analyses and model validation. Uncertainty and sensitivity analyses were conducted using techniques (Simpson and Ramsdell 1993) that were reviewed by the TSP and other experts in uncertainty and sensitivity analyses (Hoffman 1993).

- Uncertainty analyses help to determine the precision with which dose estimates can be made.
- Sensitivity analyses determine the parameters and pathways that contribute most to the dose and associated uncertainties.
- Model validation involves the comparison of model estimates with actual measurements to demonstrate the degree to which the model estimates simulate the way events actually occurred. Historical measurements from the Columbia River were used to develop many of the models that were used to estimate environmental accumulation and dose. Data from 1967, however, were not used to develop these models but reserved for validation studies.

5.1 Uncertainty and Sensitivity Analyses

The Source Term Release River Model (STRRM) (Heeb and Bates 1994) provides distributions of monthly estimates of the release of the five key radionuclides to the Columbia River from the eight single-pass plutonium production reactors on the Hanford Site. Because these monthly estimates incorporate the statistical uncertainty in the release estimates, this method is called a "stochastic" method of estimating radionuclide releases. By contrast, the Columbia River transport computer code (WSU-CHARIMA) and the river dose computer code (CRD) provide single monthly estimates without factoring in statistical uncertainty (Walters et al. 1994). The method of estimating radionuclide releases in these codes is called "deterministic." This distinction is important to this study because the deterministic codes do not directly provide uncertainty results. Thus, special analyses needed to be performed to determine the uncertainties in the dose estimates and in the parameters contributing to those uncertainties.

The following subsections explain the techniques used for uncertainty and sensitivity analyses for the WSU-CHARIMA and CRD computer codes. Section 5.1.2 then presents the estimations of statistical uncertainty in the dose assessments of two adult male individual types, the maximum and typical representative individuals. Section 5.1.3 presents the results of a sensitivity (i.e., parameter influence) analysis of maximum and typical representative individuals, both adult males, living in Richland, Washington, and downstream in The Dalles, Oregon.

5.1.1 Analysis Techniques

The uncertainty in the quantity and timing of radionuclide releases was addressed in the STRRM model. The concentrations of radionuclides in water were determined using the WSU-CHARIMA transport model. Prior analyses of WSU-CHARIMA indicated that the uncertainty in concentrations of radionuclides in water introduced by the processes modeled with WSU-CHARIMA was small when compared with the uncertainty introduced via the source term itself (Walters et al. 1994). Therefore, the uncertainty in water concentrations was estimated simply by propagating in a linear fashion the uncertainty in the monthly releases through the WSU-CHARIMA output. In other words, any increase or decrease in the source term was modeled as having a direct proportional increase or decrease in the radionuclide concentrations in the river. This technique provided for an uncertainty distribution of water concentrations that was then used as input to the CRD dose model.

The calculation of dose estimated by the CRD model requires numerous input parameters besides water concentration. These include parameters that describe the relationship between concentrations in water and concentrations in fish, waterfowl, drinking water, and other pathways by which humans might be exposed. For the HEDR Project, these parameters were developed from the available historical measurements. Many thousands of samples of fish, waterfowl, drinking water, etc., have been collected and analyzed over the history of Hanford Site operations. While these data alone are insufficient for use in estimating dose for all times, places, and diets, they provided a very strong statistical database from which to develop appropriate transfer factors. Use of this database allowed HEDR staff to prepare distributions of the input parameters for CRD. Using the input parameter distributions thus derived along with the distributions of radionuclide concentrations in water that were prepared as described above, 100 estimates of lifetime dose for representative individuals were prepared. Each of the 100 estimates was made using different inputs of concentration, transfer factor, and individual exposure. The resulting dose distribution defines the range of uncertainty contained in each individual dose. The input parameters for the CRD code and the information on parameter distributions are documented in Snyder et al. (1994).

The 100 estimates of dose for the various types of individuals, along with the 100 sets of input parameters used to calculate them, served as the starting point for the sensitivity analyses. A stepwise multiple linear regression was performed on the results of the 100 calculations and the input parameters. The increase in the coefficient of determination at each step (when a new parameter entered the regression) was used as a measure of that parameter's sensitivity (see Hoffman 1993).

5.1.2 Uncertainties in Dose Estimates

Because the CRD computer code is deterministic, doses estimated using it directly do not have an associated uncertainty. In order to provide information that could be related to the other reported doses, uncertainty estimates were prepared for two types of representative individuals at two locations. The two types of individuals were adult reference males with maximum and typical exposure patterns. The two locations were Richland, Washington, one of the locations nearest the radionuclide source, and The Dalles, Oregon, downstream of the radionuclide source. Total effective dose equivalents summed over the time period 1950-1971 were evaluated.

The estimated uncertainty ranges are illustrated in this document using boxplots. A sample boxplot is shown in Figure 5.1. Boxplots have a box that contains the middle 50 percent of the estimated values (values between the 25th and 75th percentiles). Within the box, the median (50th percentile) and mean are shown. The ends of the whiskers (straight lines extending from the box) are the 5th and 95th percentiles, which are the lower and upper subjective confidence limits of the 90-percent

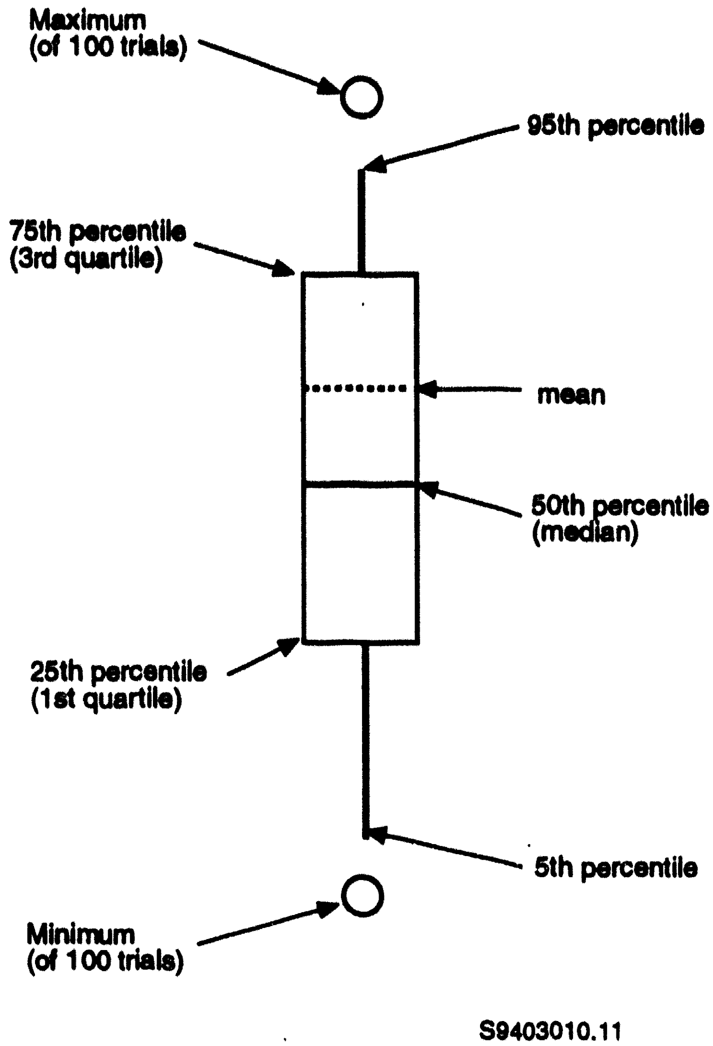


Figure 5.1. Example of a Boxplot Used to Display Uncertainty Ranges for Dose Estimates (adapted from Simpson and Ramsdell 1993)

subjective confidence interval for the dose. The minimum and maximum calculated dose values are shown by dots at either end of the boxplot. In the following figures, all of the above descriptors (minimum, maximum, mean, median, percentiles) are generated based on 100 different CRD estimates.

Cumulative effective dose equivalents over the 22-year period from 1950-1971 for maximum and typical representative individuals at Richland and The Dalles are shown as boxplots in Figure 5.2. Note that the ordinate of the figure is logarithmic; i.e., each interval is a factor 10 times larger than the one before it. These plots and the doses presented in the appendix indicate that doses to maximum representative individuals could have been about 30 times higher than those to typical representative individuals. The doses were higher upstream at Richland when compared to The Dalles for both types of individual by about a factor of 2.5. The 90-percent subjective confidence interval for each dose ranges over a factor of 4; i.e., the 95th percentile is about four times higher than the 5th percentile. The 50-percent subjective confidence interval (the middle two quartiles) is well under a factor of 2.

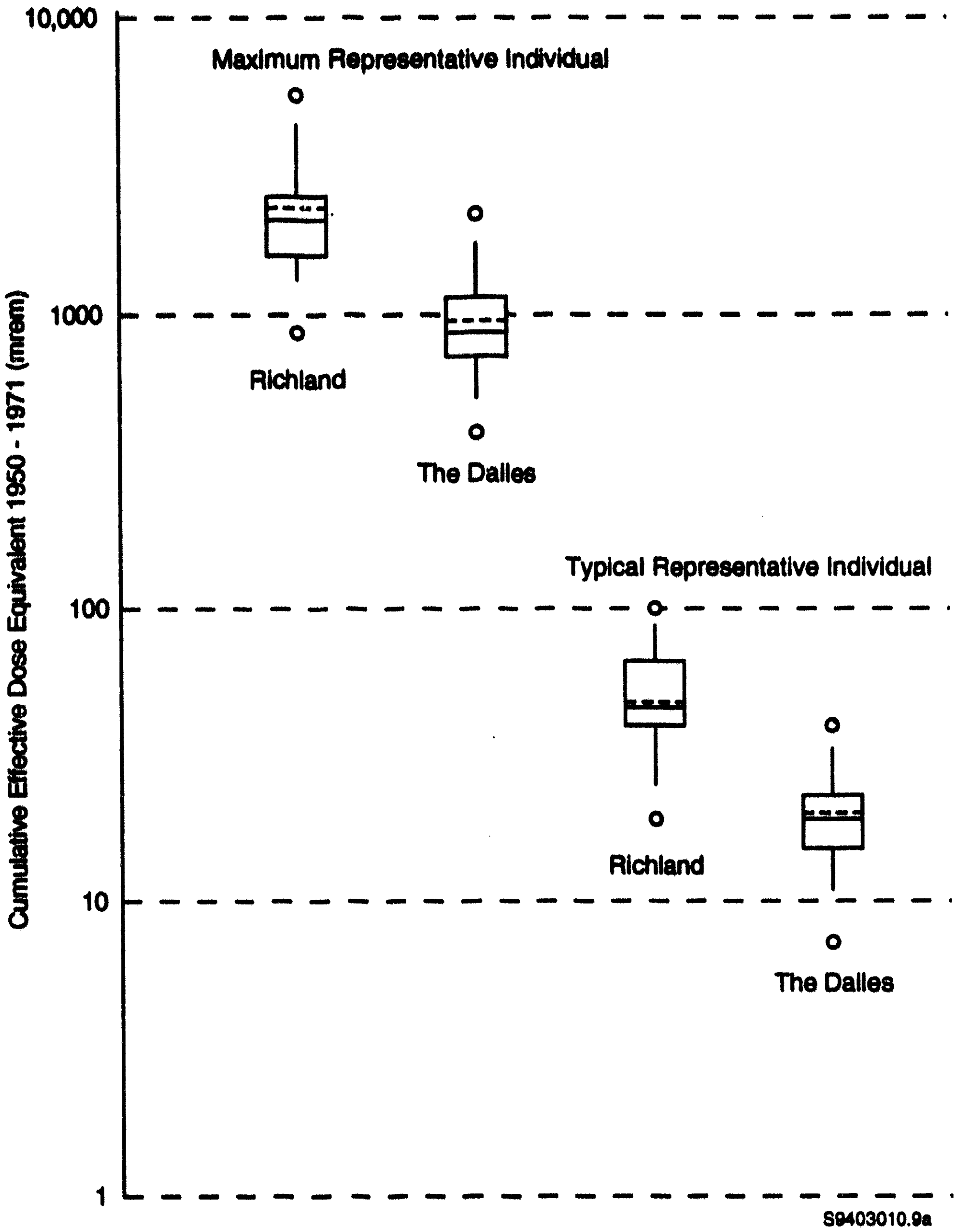


Figure 5.2. Uncertainty in Effective Dose Equivalent for Two Types of Individuals at Richland, Washington, and The Dalles, Oregon, 1950-1971

The cumulative effective dose equivalent shown in Figure 5.2 is made up of the weighted sum of doses to a number of organs. Figures 5.3 and 5.4 show uncertainties in doses to two organs of interest. Figure 5.3 illustrates the uncertainties in dose to the lower large intestine, the organ receiving the highest dose in the body. Figure 5.4 illustrates the uncertair ..s in dose to red bone marrow. Comparison of Figure 5.3 with Figure 5.2 shows that there is more variability in the uncertainty of dose to the lower large intestine than there is to the effective dose. This is because the dose to the lower large intestine is dominated by contributions from the shorter-lived radionuclides. Doses and uncertainties for The Dalles are smaller than for Richland, largely because the longer travel time to The Dalles allows the decay of the shorter half-life radionuclides, sodium-24, arsenic-76, and neptunium-239. The uncertainties in dose to red bone marrow shown in Figure 5.4 more nearly conform to the effective dose equivalent because red bone marrow doses are dominated by the longer-lived radionuclides, phosphorus-32 and zinc-65. Because there is relatively little radioactive decay of these radionuclides during the transit time from Richland to The Dalles, the main source of dose decrease comes from dilution by inflowing Columbia River tributaries such as the Snake River.

The cumulative effective dose equivalent shown in Figure 5.2 is made up of contributions from several exposure pathways. Each pathway has uncertainty associated with it. The uncertainties in the 22-year cumulative dose for the calculated exposure pathways for the maximum individual at Richland are shown in Figure 5.5. This figure shows that total dose is controlled by the ingestion of resident fish and waterfowl. The pathway with the greatest uncertainty is the dose from ingestion of salmon, for which the 90-percent subjective confidence interval ranges over a factor of 30 (from 0.12 to 3.65 millirem over 22 years). However, the absolute magnitude of the dose received by salmon ingestion is so small that it contributes less than 1 percent to the total dose. This indicates that while the HEDR Project is quite uncertain about the dose from salmon ingestion, additional efforts to refine the salmon dose are not warranted.

The uncertainties about the pathways contributing to dose for the maximum individual at The Dalles are shown in Figure 5.6. The uncertainties about the minor contributors of external dose and drinking water dose are less than those for Richland because the short-lived radionuclides have decayed. The uncertainties for shellfish and salmon are the same as for Richland because these foods came from the same sources at both locations. The absolute dose from resident fish and waterfowl is somewhat lower at The Dalles than in Richland because there is more dilution, but as the contributing radionuclides are the same, the range of uncertainty is about the same at both locations.

5.1.3 Key Model Parameters

Individual dose is made up of the sum of the contributions from multiple radionuclides over multiple exposure pathways. Different types of individuals, exposed via different pathways, will have different doses influenced by different parameters. The purpose of a sensitivity analysis is to determine which parameters have the greatest influence on the uncertainty. Thus, each type of individual at each location requires a separate sensitivity analysis to precisely determine the key parameters. The results of the sensitivity analysis for the maximum and typical representative individuals at the near-source (Richland) location and the downstream (The Dalles) location are presented in this section.

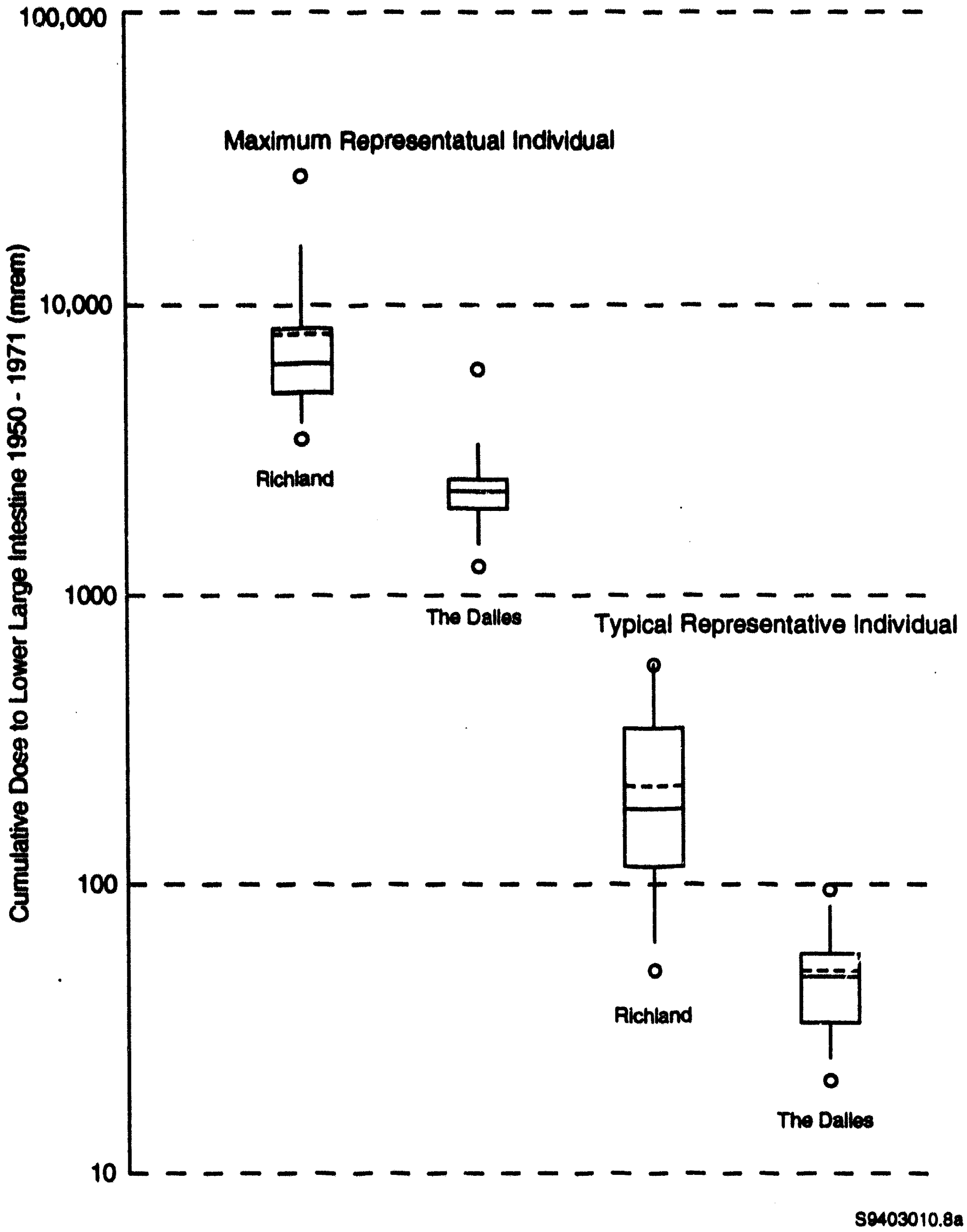


Figure 5.3. Uncertainty in Dose Equivalent to Lower Large Intestine for Two Types of Individuals at Richland, Washington, and The Dalles, Oregon, 1950-1971

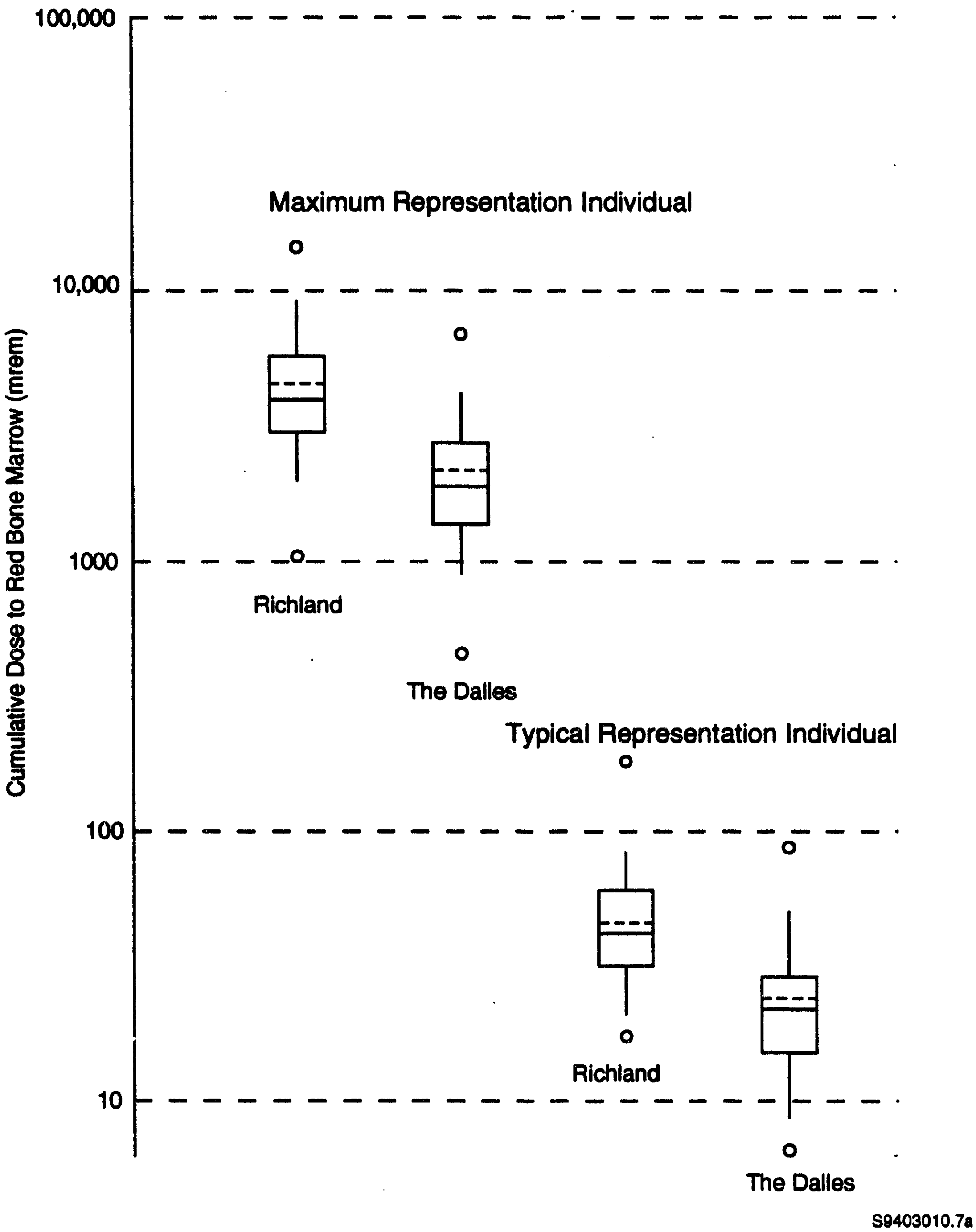


Figure 5.4. Uncertainty in Dose Equivalent to Red Bone Marrow for Two Types of Individuals at Richland, Washington, and The Dalles, Oregon, 1950-1971

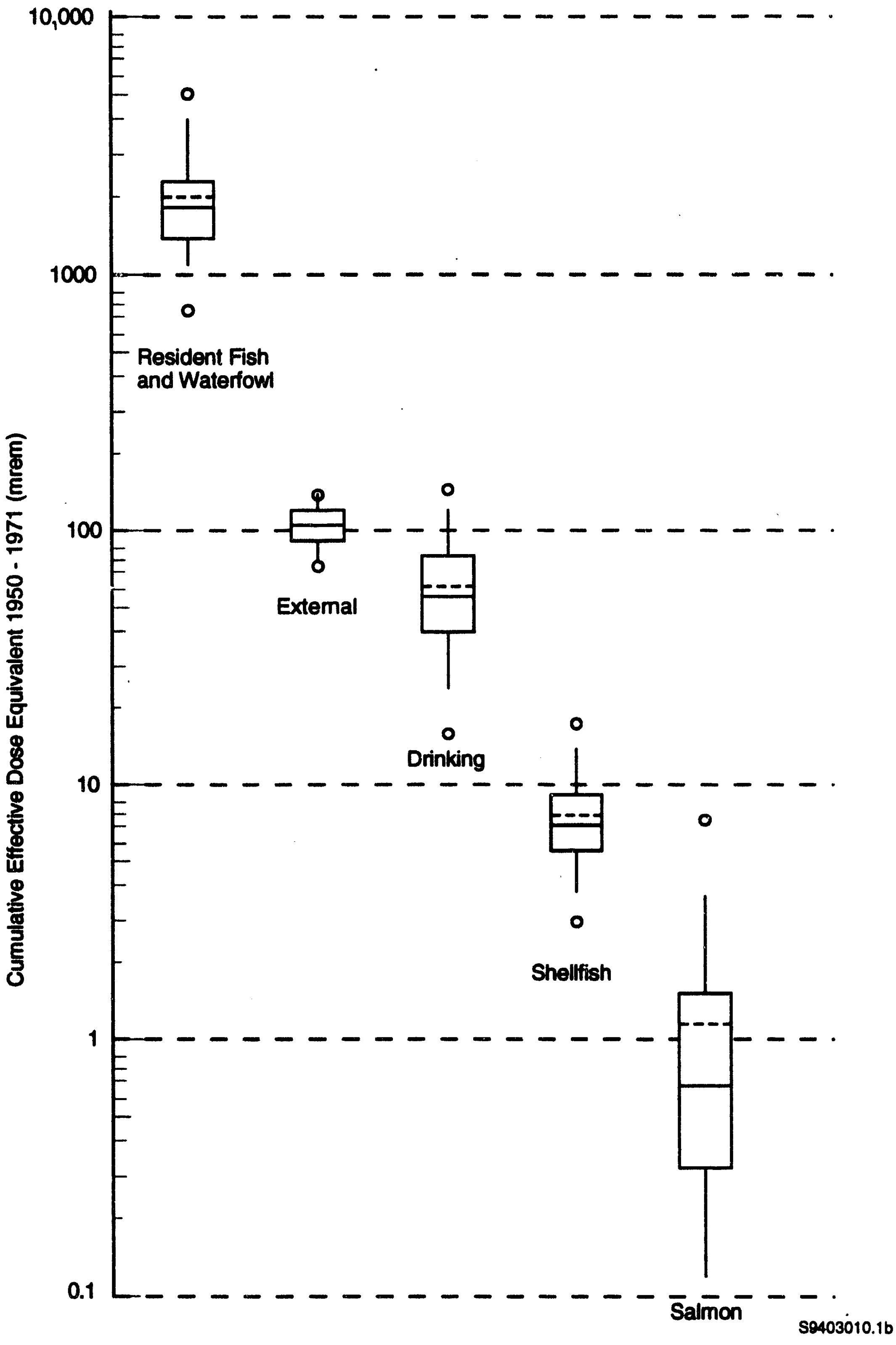


Figure 5.5. Uncertainty in Pathway Contribution to Effective Dose Equivalent for a Maximum Representative Individual at Richland, Washington, 1950-1971

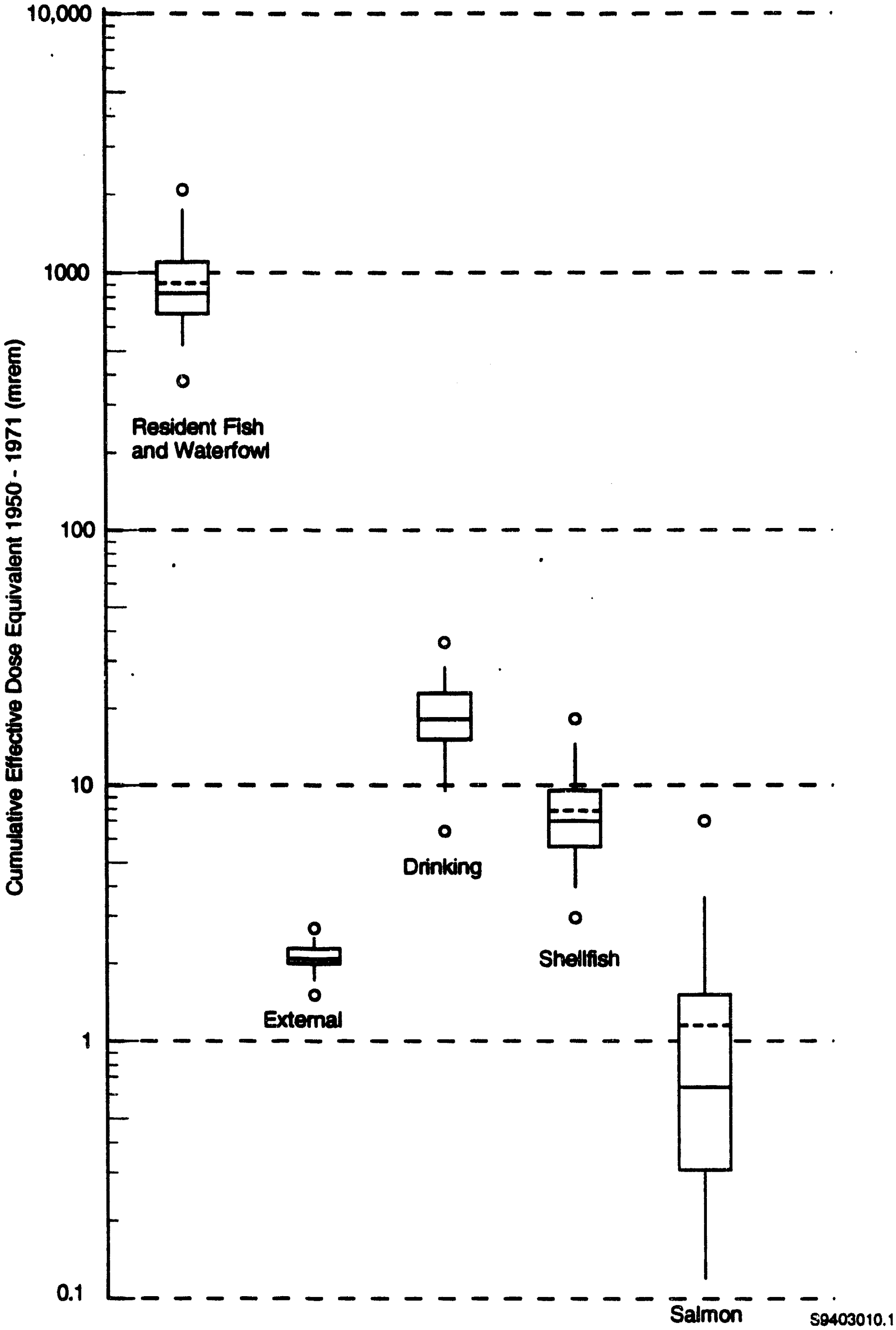


Figure 5.6. Uncertainty in Pathway Contribution to Effective Dose Equivalent for a Maximum Representative Individual at The Dalles, Oregon, 1950-1971

The uncertainty in the final dose is because of the contributions from the uncertainties in both the pathways and individual radionuclides. This is illustrated in Figure 5.7, which shows the uncertainty about the total effective dose equivalent for a maximum representative individual at Richland. The uncertainty in calculations of the total effective dose equivalent is apportioned as follows. Pie chart (A) shows the relative contribution to uncertainty in the effective dose equivalent from arsenic-76, phosphorus-32, and zinc-65. The largest contributor to the uncertainty involves dose from arsenic-76, followed by doses from phosphorus-32 and zinc-65. The uncertainties from the remaining radionuclides contribute only a small amount to the total uncertainty. Pie charts (B), (C), and (D) show a breakdown by pathway of the uncertainties in the total dose for each radionuclide. As shown in pie chart (B), the parameter with the largest sensitivity in the component of dose from arsenic-76 is the holdup time between catching and ingesting resident predatory fish. The second most sensitive parameter is the water-to-fish bioconcentration factor. Pie chart (C) shows that the parameter with the largest sensitivity in the component of dose from phosphorus-32 is the variability of the factor for conversion of ingested amount to dose, followed by the bioconcentration factors for waterfowl and fish. The uncertainty in dose from zinc-65 shown in pie chart (D) is largely a result of the uncertainty in the ingestion dose conversion factor.

The contributions of particular parameters to uncertainty, shown in pie charts (A), (B), (C), and (D), are summarized in pie chart (E). Pie chart (E) shows that for a maximum individual in Richland, the input parameter with the largest influence on uncertainty is the ingestion dose conversion factor for zinc-65. The next largest influences are caused by the ingestion dose conversion factor for phosphorus-32 and the holdup time from time of catch to ingestion of predator fish. The holdup time from catch to ingestion for predatory fish is next. It is apparent from this pie chart that many factors combine to define the final uncertainty. However, five parameters together account for 75 percent of the total uncertainty.

Pie charts are presented for both maximum and typical representative individuals at Richland and The Dalles. The results of the sensitivity analyses for effective dose equivalent are shown in Figure 5.8. Note that the pie chart for a maximum individual in Richland, shown in the top left of Figure 5.8, is pie chart (E) described in Figure 5.7. Figure 5.8 shows that the factors contributing to overall uncertainty vary between the maximum and typical representative individuals at a single location. The factors contributing to overall uncertainty for a given representative individual type are also dependent on the location of exposure. Uncertainties in the dose received by a maximum individual at Richland and The Dalles are both dominated by contributions to the dose from zinc-65, but the percentage contribution is different at the two locations.

Figures 5.9 and 5.10 provide similar sets of pie charts showing uncertainty in doses to the lower large intestine (the organ with the largest dose) and red bone marrow, respectively. The parameters for dose conversion factor, holdup, and bioconcentration factors are all important contributors to the overall uncertainty. Each has a different degree of importance depending on the location and mode of exposure of the reference individual.

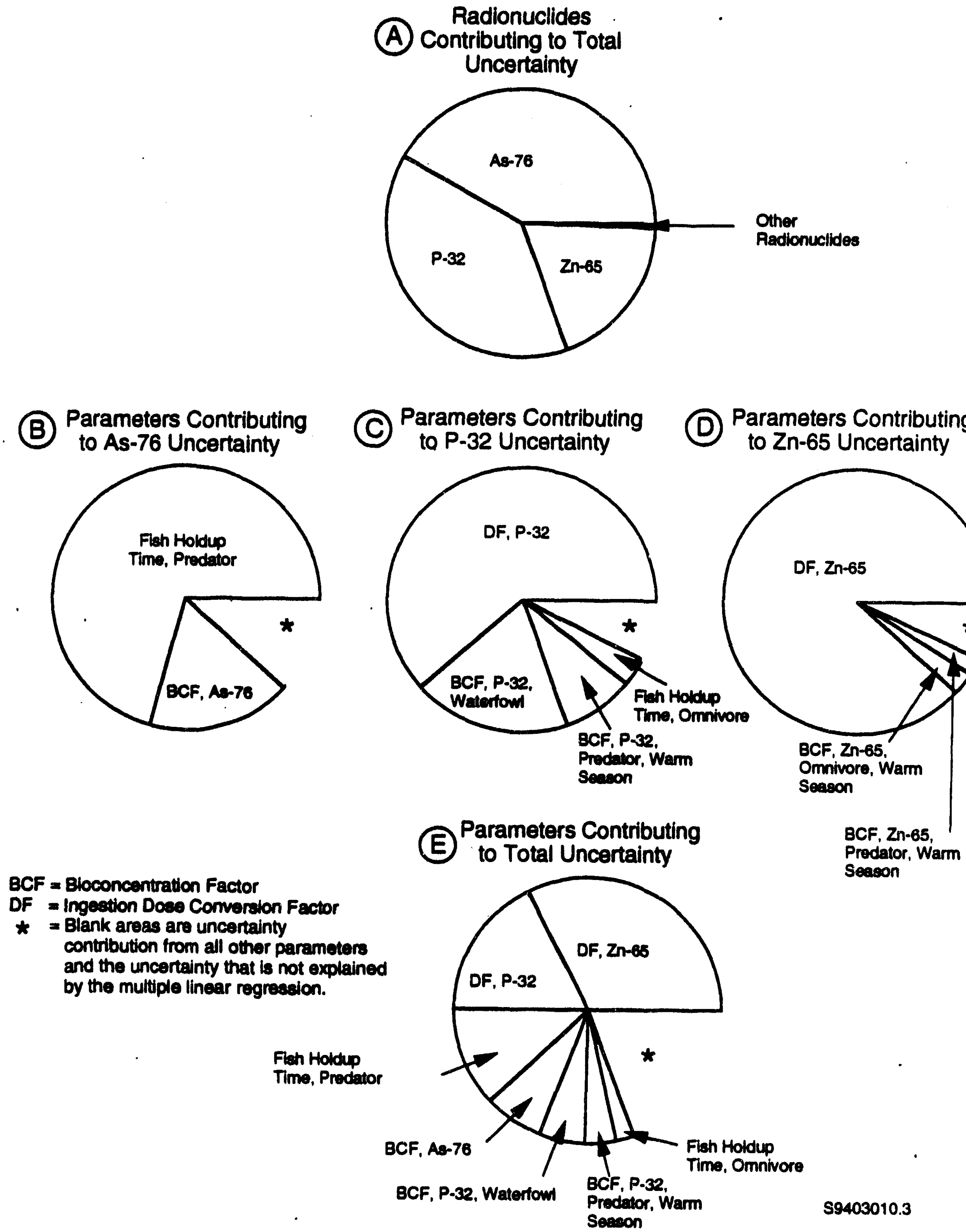


Figure 5.7. Parameters Contributing to Uncertainty of Dose to a Maximum Representative Individual in Richland, Washington

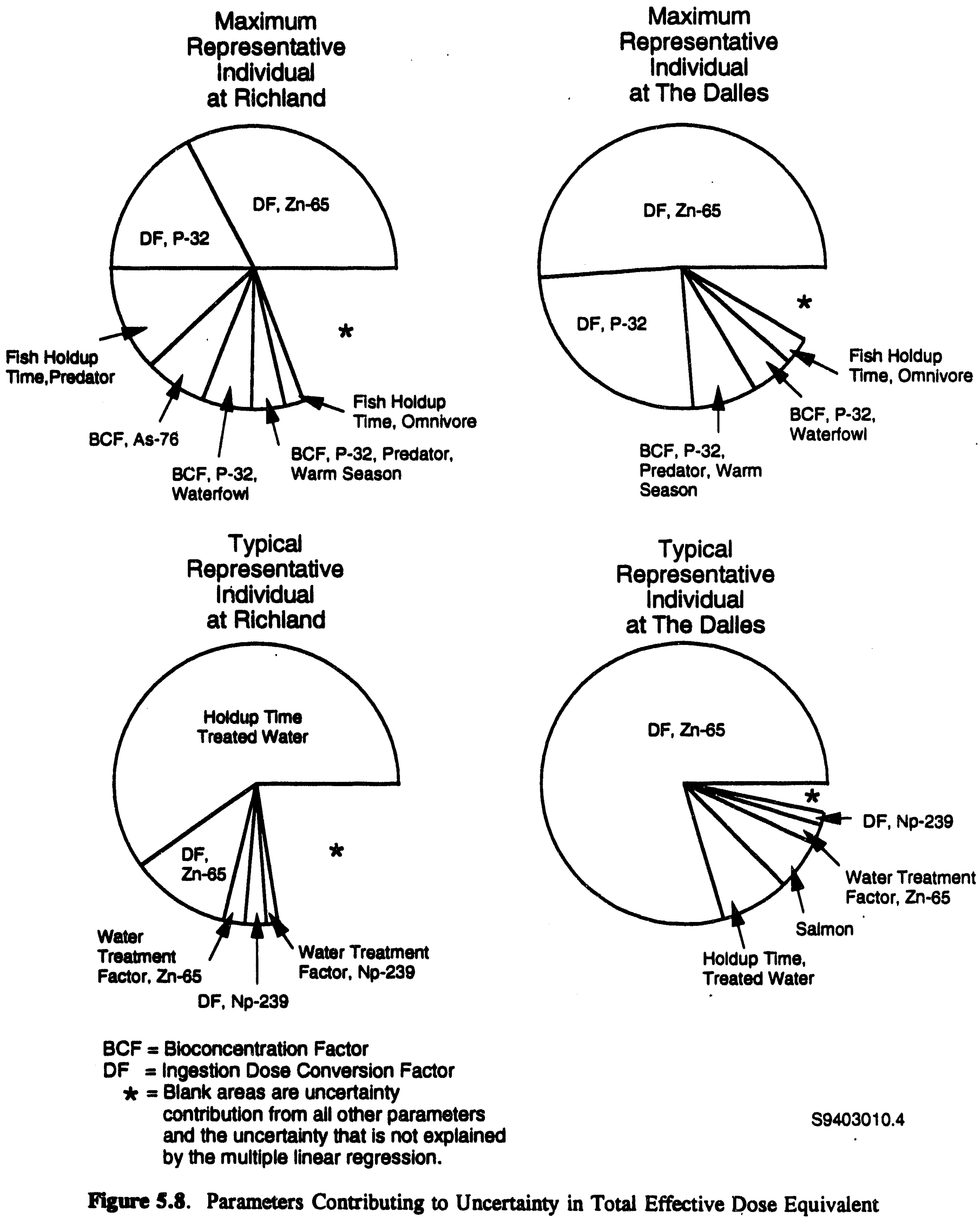
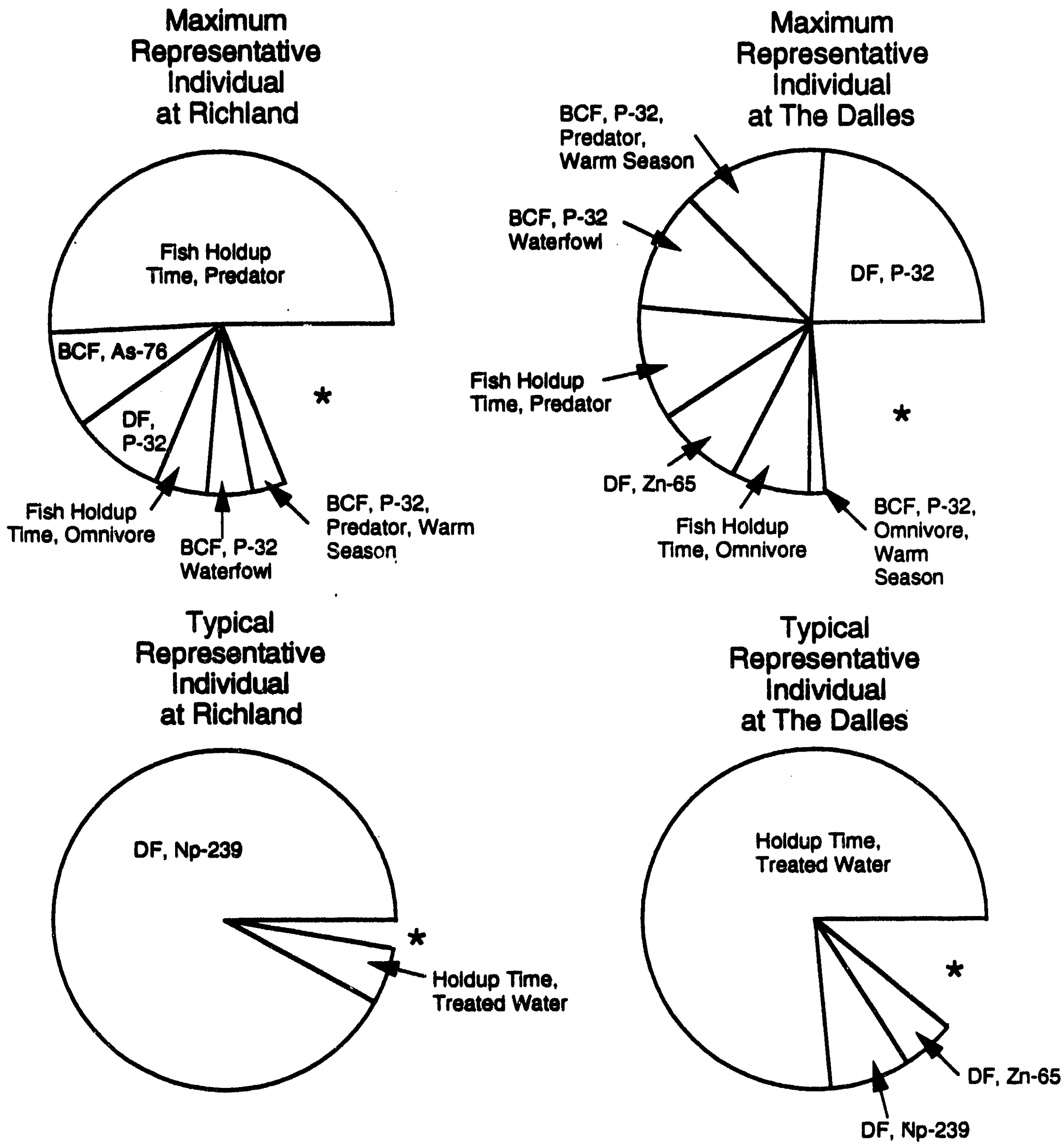


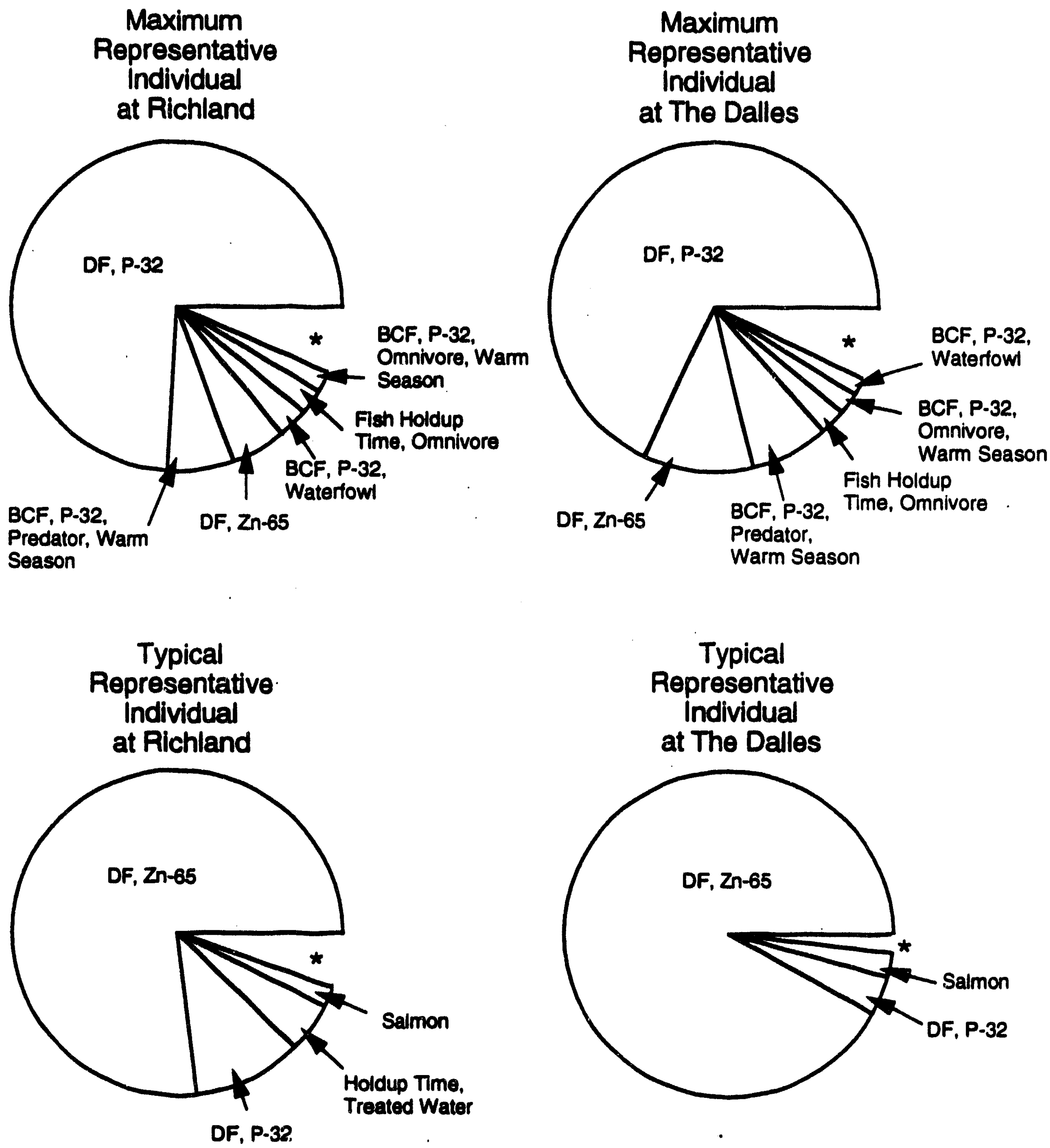
Figure 5.8. Parameters Contributing to Uncertainty in Total Effective Dose Equivalent



BCF = Bioconcentration Factor
DF = Ingestion Dose Conversion Factor
* = Blank areas are uncertainty contribution from all other parameters and the uncertainty that is not explained by the multiple linear regression.

S9403010.5

Figure 5.9. Parameters Contributing to Uncertainty in Dose Equivalent to Lower Large Intestine



BCF = Bioconcentration Factor
DF = Ingestion Dose Conversion Factor
* = Blank areas are uncertainty contribution from all other parameters and the uncertainty that is not explained by the multiple linear regression.

S9403010.6

Figure 5.10. Parameters Contributing to Uncertainty in Dose Equivalent to Red Bone Marrow

5.2 Model Validation

Model validation of the WSU-CHARIMA and CRD computer codes consists of comparing historical measurements to model estimations in three areas: dose model inputs (i.e., source term, transport, and bioconcentration factor data input to the codes) for radionuclide concentrations in water, fish, and shellfish; reference individual doses (using measured whole body burdens) for an adult male living in Richland, Washington; and real individual doses (using a well-documented individual's intake of zinc-65 in Columbia River whitefish). Napier et al. (1994) present a complete summary of the validation exercises conducted for the HEDR Project.

5.2.1 Validation of Dose Model Inputs

Model input data were validated for the WSU-CHARIMA code for concentrations of radionuclides in water and for the CRD code for concentrations in fish and Willapa Bay oysters.

Concentration of radionuclides in water depends on both the source term and transport calculations. A direct comparison of estimated values and historical measurements has been made with the WSU-CHARIMA modeling outputs. Validation of those outputs serves as indirect validation of the river source term release model, STRRM, as well as WSU-CHARIMA itself. Computed concentrations of radionuclides in Columbia River water were compared with the monthly grab and composite water samples taken at various sampling locations. A complete description of the comparisons for each radionuclide at each location for the years 1960 through 1970 is provided in Walters et al. (1994). The estimated and measured values for the composite samples (which best approximate the monthly averaging used for the simulation) track very well. The estimated values always fall within the scatter of the available historical measurements for each month. Estimated and measured values are always well within a factor of 2 of each other. Similar results are obtained with the grab samples. The overall uncertainties in the estimated river water concentrations are small and are dominated more by the uncertainties in the source term from STRRM than by the uncertainties in the transport calculation.

The concentration of radionuclides in fish depends on the source term and transport estimates, and on the bioconcentration modeled in CRD. Direct comparison of estimated values to historical measurements was made with CRD intermediate outputs. Validation of those outputs serves as indirect validation of the river source term and transport models.

Ratios were made of the estimated concentrations of radionuclides in three general types of fish to the average of those measured in the Ringold, Kennewick/Pasco, and Snake/Walla Walla River segments of the Columbia River. Analyses were performed for each month, location, and species. The radionuclide concentrations in the measured samples were quite variable, often ranging over two orders of magnitude for a given type of fish at a given location for any one month.

Estimates for sodium-24 were calculated for the Ringold segment of the Columbia River, the only location for which measurement data were available. The average of monthly ratios of the estimated value to the mean measured value is 0.77, indicating that for the year 1967 the estimates were about 26 percent lower than the historical measurements (Napier et al. 1994).

Estimates for phosphorus-32 at Ringold were similar to those for sodium-24. The annual average ratio of monthly phosphorus-32 estimates/measurements was 0.76. However, the estimated/measured ratio for phosphorus-32 was not as close at other locations, reaching a maximum of 17 for omnivorous fish in the Kennewick/Pasco segment of the river. Overestimates were highest in the early portion of the year, when the "cool season" bioconcentration factor was used. Estimates were closer to the measurements in the other months. This pattern was similar, but much less pronounced, for the other fish types and other locations. The initial data used to develop the cool season phosphorus-32 bioconcentration factor were extremely variable (the 90-percent confidence interval of the resulting bioconcentration factor covers two orders of magnitude), so some variability of this type should be expected. In addition, the overestimation appeared to be highest for the Kennewick/Pasco location. All fish from this location were caught at a sampling area known as Island View, near the mouth of the Yakima River. It is possible that the fish at this location were living largely in water from the Yakima River, and thus were not as highly exposed as the model estimated.

The model appeared to slightly overestimate the bioconcentration of zinc-65. Compared to historical measurements from 1967, for all fish types at all locations, the model overestimated the average monthly concentrations in fish by about a factor of 3, although a few monthly averages were underestimated by the model. The overestimates were highest for omnivorous fish in the cooler months and also appeared to be highest for the Kennewick/Pasco location. As was the case with phosphorus-32, all fish from Kennewick/Pasco were caught at the Island View location. This supports the suggestion that the fish at this location were living largely in water from the Yakima River and thus were not as highly exposed as assumed by the model.

Concentrations of zinc-65 in Pacific Ocean shellfish (oysters) were prepared as annual averages for application to all locations because the major source of contamination in the shellfish is a chronic, dilute source in the Pacific Ocean. The concentrations are based on annual cumulative source terms and the historical measurements from Willapa Bay oysters. Data are available for every year in the decade of the 1960s. Most of these data were used to develop the functional relationships, but the 1967 data were reserved for validation. The model estimate is within 40 percent of the 1967 measurements. For the entire decade of the 1960s, the model resulted in an underestimation of about 10 percent below the measurements. The CRD implementation of this model is based on the simple relation of emissions to concentrations in oysters for the period prior to the initiation of the measurements. For the period 1959 through 1971, the published summaries of environmental measurements are used in the CRD calculations, so the dose estimates for this period are based directly on measured data, not on the approximation of the model. The model estimates are used only for the period prior to 1959.

5.2.2 Validation of Reference Individual Doses

Tens of thousands of whole body radioactivity measurements have been made on Hanford workers employed in Hanford operations from 1959 to the present. Almost all of the whole body counts taken during the period of reactor operation indicate the presence of Hanford originated zinc-65 and sodium-24 (Swanberg 1962). The river dose model incorporated in CRD was used to obtain the monthly intake values for the Richland location. Intake for a reference adult male individual living in Richland was used. For the purpose of model validation, body burden, rather than dose, of the radionuclides was estimated. This provided indirect validation of the source terms and the WSU-CHARIMA transport model as well as the CRD formulation. Use of the Richland individual allowed an additional comparison to be made. The Richland Columbia River water treatment plant initiated operations in October 1963 and a step increase in body burden was anticipated for this date. The reference adult male used in the calculations was assumed to live in Richland and to ingest 1 liter per day of treated Columbia River water while at home. Uptake and retention in the body were modeled using the parameters used by the International Commission on Radiological Protection (ICRP) in developing the ingestion dose factors used in the CRD code. The comparison is made with the distribution of body burdens in the complete database.

The result of the comparison of measured whole body counts and model estimations for sodium-24 is shown in Figure 5.11. Figure 5.11 shows the comparison of just the median measurements with the model estimates. The model estimate assumes ingestion beginning when the Richland water source became available in October 1963. The figure shows that before October 1963 there was little exposure of the workers to sodium-24 from routinely recurring sources such as drinking water. Starting in late 1963, the estimates compare well in both magnitude and temporal pattern with the measurements. The greatest single monthly deviation of measured versus estimated body burden is a factor of 4, and the long-term ratio of estimates to measurements is 1.40. The HEDR estimations, with few exceptions, fall between the 25th and 75th percentiles of the measured distributions and always fall within the range of the measured data.

Figure 5.12 shows the comparison of measured whole body counts and model estimates for zinc-65. Following the October 1963 startup of the Richland water treatment plant, the calculated body burden of zinc-65 rose to very closely follow the median of the measured values. The long-term average ratio of estimate to measurement is 1.39.

5.2.3 Validation of Real Individual Doses

An experiment was conducted by Hanford scientists between January 1962 and late 1963, in which a single investigator ingested whitefish containing measured quantities of zinc-65 from the Columbia River at regular intervals (Foster and Honstead 1967). His body burden of zinc-65 was then measured weekly. The body burdens reported in Foster and Honstead (1967, p. 41) also appear in the Hanford database. They are among the highest recorded and are the highest in the database for the entire period of the experiment, making them easy to extract from the Hanford historical measurements base.

For use in validating the HEDR model, the course of the experiment was simulated as an individual ingesting 220 grams/week of Richland whitefish (the average amount reported in the description of the experiment) in addition to 1 liter/day of treated Columbia River water. As shown in Section 4.2 (Table 4.4), these are the two most important exposure pathways for a maximum representative individual at Richland. The concentrations of zinc-65 in the whitefish were estimated using the bioconcentration factors derived for the HEDR Project. Body burden was estimated using the same uptake and retention parameters used by the ICRP in developing the ingestion dose factors used in the CRD code.

The results of the estimate are compared to the measurements (reported and in the Hanford database) in Figure 5.13. The estimated and measured lines are very similar and agreement could

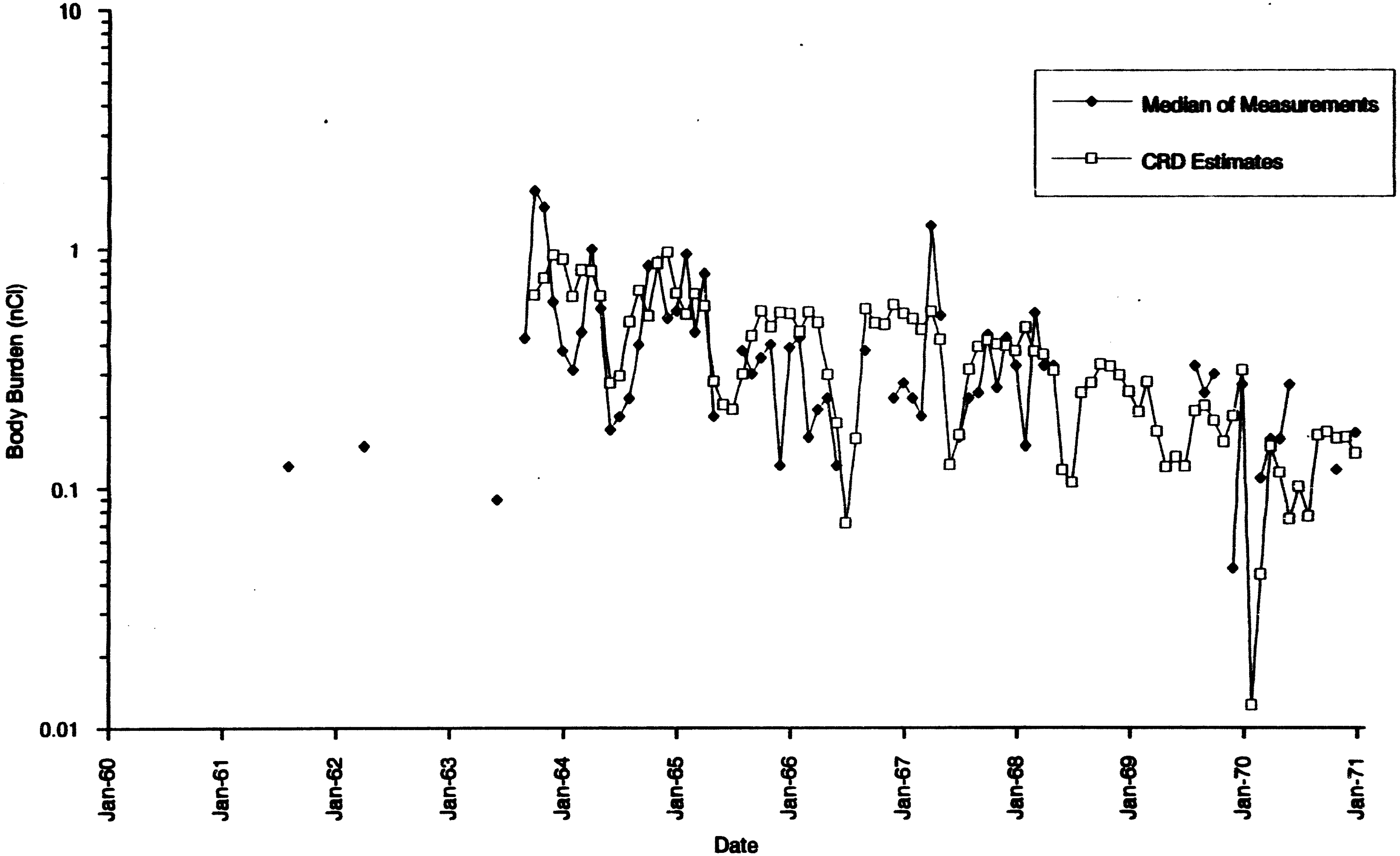


Figure 5.11. Sodium-24 Comparison of Whole Body Counts and Model Estimates (from Napier et al. 1994)

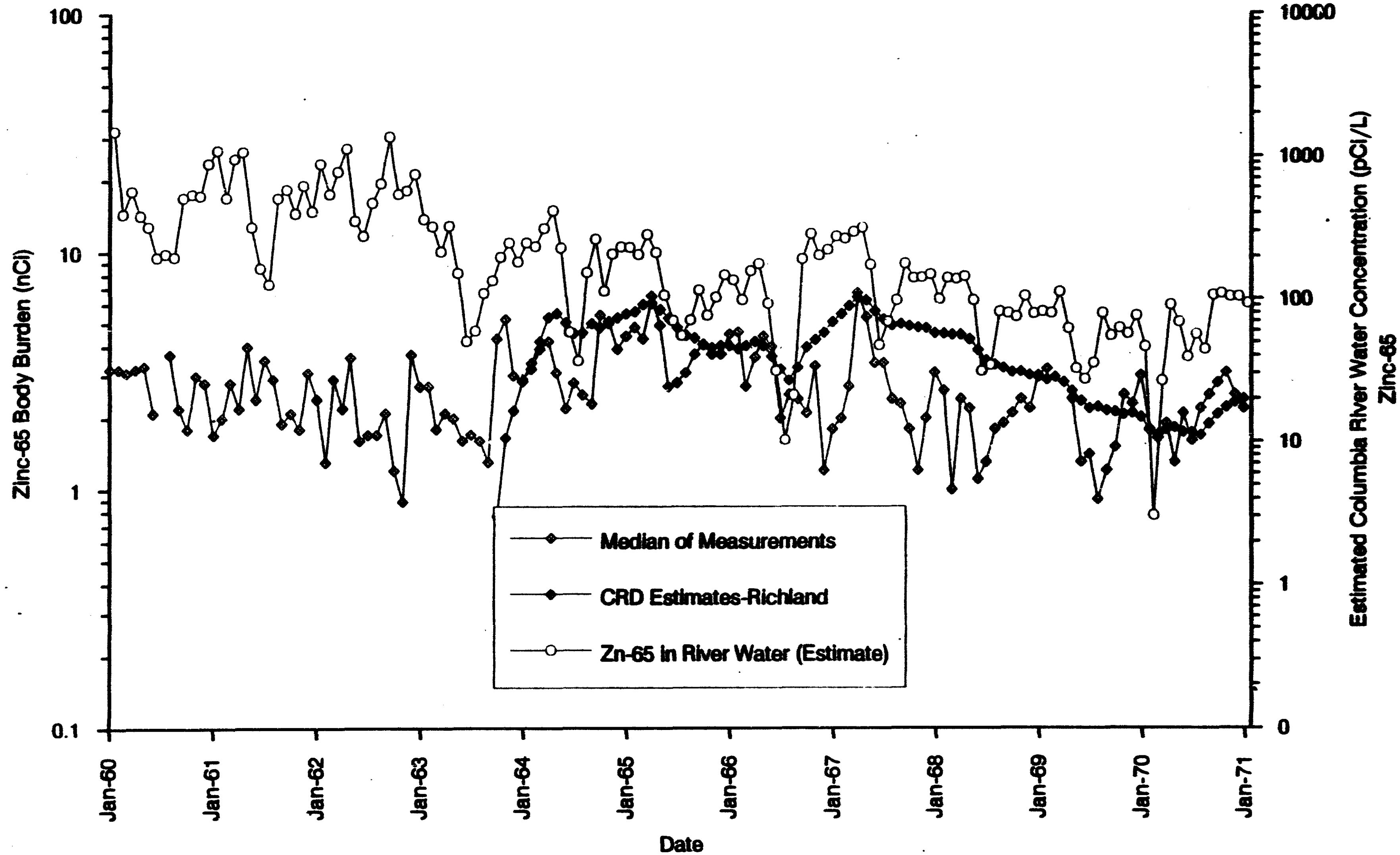


Figure 5.12. Zinc-65 Comparison of Whole Body Counts and Model Fstimates (from Napier et al. 1994)

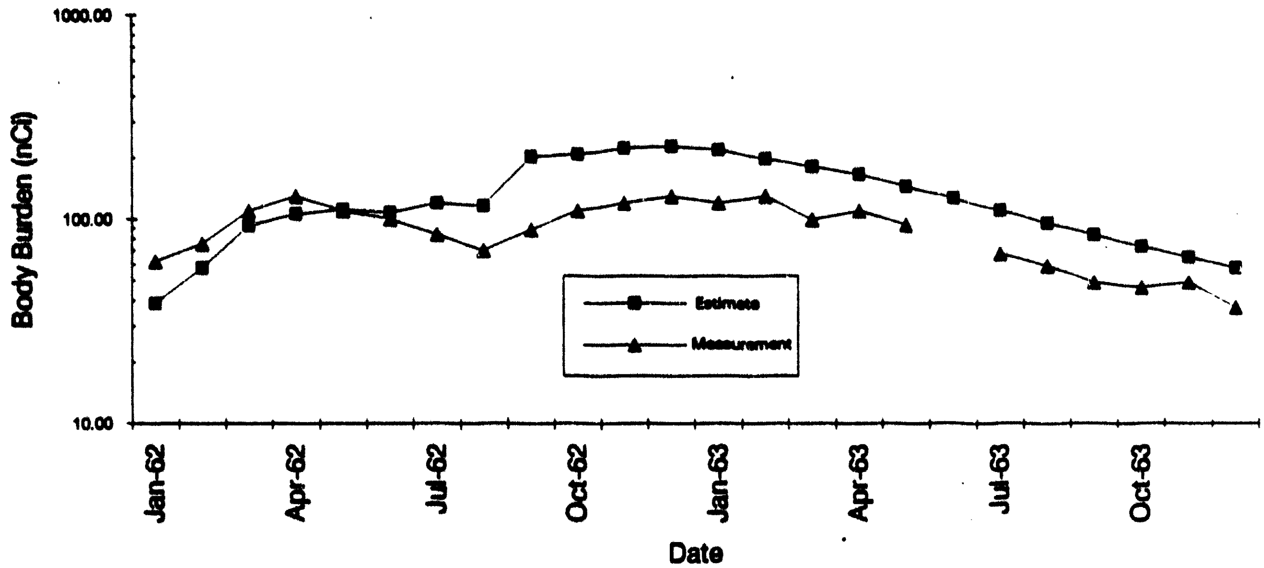


Figure 5.13. Estimated and Measured Zinc-65 Body Burden (from Napier et al. 1994)

have been even better because the investigator's assimilation and retention of zinc-65 deviated significantly from the published ICRP values. This comparison indicates that if the ingestion rates of locally caught fish can be determined, the estimates of radiation dose should have very small biases.

AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

2 of 2

6.0 Conclusions

- Reliable and useful doses and their uncertainties have been reconstructed for possible exposures of representative individuals from historical releases of materials from the Hanford Site.

- The most important means of exposure via the river pathway was consumption of resident fish.

- The most important contributors to dose were zinc-65 and phosphorus-32, respectively, released from the single-pass reactors.

- The highest estimated dose was from resident fish caught in the Columbia River at Ringold, downstream of the Hanford reactors.

- The highest estimated dose was to an adult consuming 40 kilograms (90 pounds) of resident fish from the Columbia River at Ringold (median dose of 140 millirem to the whole body for 1960).

- The highest estimated dose to a typical adult was accumulated during the 1956-1965 time period with 1960 being the highest year (median dose of 5 millirem) at Pasco, Washington.

- The most important contributors to uncertainty in the dose estimates were the dose factor and the bioconcentration factors, respectively.

- Representative individual doses included in this report allow individuals using the Columbia River commercially, for recreation, or as a source of water or foods to estimate their doses.

This report is the culmination of technical work performed to reconstruct doses that may have been received by persons who used the Columbia River from 1944 through 1992 for food, recreation, or commercial purposes. It summarizes the efforts to estimate 1) the quantity and timing of releases of radioactive materials to the river, 2) the transport, dilution, and decay of radioactive materials from the release points to the vicinity of Portland, Oregon, 3) the accumulation of radioactive materials in Columbia River water, fish, waterfowl, and oysters exposed to the Columbia River and adjacent ocean bays, and 4) the doses that representative individuals may have received from 1944-1992.

The HEDR Project staff have been able to identify and retrieve sufficient historical information to reconstruct, through computer modeling, the operational history of each of the eight Hanford single-pass production reactors. The results of this modeling along with recorded effluent monitoring and analytical data have been sufficient to quantify release of radioactive materials to the Columbia River. The modeling and historical measurements also have been adequate to identify and quantify the major sources of uncertainty both in the variability of parameters needed for calculations and in areas where information was missing.

Historical environmental measurements and the river transport code WSU-CHARIMA have been used to reconstruct the seasonal and dam-controlled flows of the Columbia River over the period of reactor operations, 1944-1971. Validation studies using environmental historical measurements have demonstrated the acceptability of using the computer codes to estimate radioactivity concentrations in the river for important times and locations.

The use of historical environmental measurements alone was inadequate for determining concentrations of radioactive materials in fish, waterfowl, and oysters affected by the Columbia River for times and locations of interest. However, the use of historical environmental measurements for fish along with concentrations of radioactive materials in the river water calculated by the WSU-CHARIMA code have been adequate to determine bioconcentration factors for fish for times and locations of interest. Historical environmental measurements for shellfish were adequate for dose estimating. There was sufficient information to quantify the variability of bioconcentration factors and to quantify the uncertainties of the historical measurements.

The reconstruction of concentrations of radioactive materials in Columbia River water, fish, waterfowl, and shellfish affected by the Columbia River and the determination of uncertainties in the estimates provide a sound basis for estimating doses that persons may have received from exposure to river media. Models and other parametric values necessary for estimating doses were summarized from open literature publications and have been peer-reviewed.

Results of independent testing of computer codes, statistical analyses of data, uncertainty analyses, sensitivity analyses, and validation studies demonstrate that the reconstruction of reactor operations, releases of radioactive materials to the river, transport of radioactive materials in the river, accumulation of radioactive materials in biota exposed to the Columbia River, and estimation of doses to representative individuals from use of the river and associated media are appropriate and fully meet HEDR Project objectives.

7.0 References

Beetle, T.M. 1972. *A Statistical Study of Radiation Damage for Fishermen*. BNWL-SA-4449, Battelle Northwest Laboratory, Richland, Washington.

Brown, M.E., ed. 1957. *The Physiology of Fishes, Volume A - Metabolism*. Academic Press, New York.

Bramson, P.E., and J.P. Corley. 1973. *Environmental Surveillance at Hanford for CY-1972*. BNWL-1727, Battelle Northwest Laboratory, Richland, Washington.

Denham, D.H., R.L. Dirkes, R.W. Hanf, T.M. Poston, M.E. Thiede, and R.K. Woodruff. 1993. *Phase I Summaries of Radionuclide Concentration Data for Vegetation, River Water, Drinking Water, and Fish*. PNWD-2145 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

DOE - U.S. Department of Energy. 1988. *Internal Dose Conversion Factors for Calculation of Dose to the Public*. DOE/EH-0071, U.S. Department of Energy, Washington, DC.

Endres, G.W.R., J.K. Soldat, D.B. Shipler, N.M. Robinson, F.N. Eichner, and J.F. Honsted. 1972. *Dietary and Body Burden Data and Dose Estimates for Local School Children and Teenagers*. U.S. Environmental Protection Agency Research Report No. 1/-80054-3, Battelle, Pacific Northwest Laboratories, Richland, Washington.

EPA - U.S. Environmental Protection Agency. 1988. *Limiting Values of Radionuclide Intake and Air Concentrations and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. Federal Guidance Report No. 11, EPA-520/1-88-020, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, DC.

EPA - U.S. Environmental Protection Agency. 1989. *Exposure Factors Handbook*. EPA/600//8-89/043, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, DC.

Essig, T.H., and J.K. Soldat, eds. 1967. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1966*. BNWL-439, Battelle Northwest Laboratory, Richland, Washington.

Essig, T.H., G.W. Endres, J.K. Soldat, and J.F. Honstead. 1973. *Concentrations of Zn-65 in Marine Foodstuffs and Pacific Coastal Residents*. IAEA-SM-158/43, International Atomic Energy Agency, Vienna.

Farris, W.T. 1993. *Software Requirements Specifications for Columbia River Pathway: Source Term, River Transport, Environmental Accumulation and Dose Models*. BN-SA-3799 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Fix, J.J. 1975. *Environmental Surveillance at Hanford for CY-1974*. BNWL-1910, Battelle Northwest Laboratory, Richland, Washington.

Fix, J.J., P.J. Blumer, G.R. Hoenes, and P.E. Bramson. 1977. *Environmental Surveillance at Hanford for CY-1976*. BNWL-2142, Battelle Northwest Laboratory, Richland, Washington.

Foerster, R.E. 1968. *The Sockeye Salmon, Oncorhynchus nerka*. Fisheries Research Board of Canada, Ottawa.

Foster, R.F., and J.F. Honstead. 1967. "Accumulation of Zinc-65 from Prolonged Consumption of Columbia River Fish." *Health Physics* 13(1):39-43.

Foster, R.F., and R.H. Wilson. 1962. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1961*. HW-71999, General Electric Company, Hanford Atomic Products Operation, Richland, Washington.

Freshley, M.D., and P.D. Thorne. 1992. *Ground-Water Contribution to Dose from Past Hanford Operations*. PNWD-1974 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Groves, L.R. 1962. *Now it Can be Told: The Story of the Manhattan Project*. Harbor and Brothers, New York.

Hanf, R.W., R.L. Dirkes, and J.P. Duncan. 1992. *Radioactive Contamination of Fish, Shellfish, and Waterfowl Exposed to Hanford Effluents: Annual Summaries, 1945-1972*. PNWD-1986 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Heeb, C.M., and D.J. Bates. 1994. *Radionuclide Releases to the Columbia River from Hanford Operations, 1944-1971*. PNWD-2223 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Hoffman, F.O., W.J. Conover, M. Henrion, E. Hofer, and S. Simon. 1993. *Peer Review of HEDR Uncertainty and Sensitivity Analyses Plan*. PNWD-2162 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Holly, F.M., Jr., J.C. Yang, P. Schwarz, J. Schaefer, S.H. Hsu, and R. Einhellig. 1993. *CHARIMA--Numerical Simulation of Unsteady Water and Sediment Movement in Multiple Connected Networks of Mobile-Bed Channels*. IIHR Report No. 343, Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa.

Houston, J.R., and P.J. Blumer. 1978. *Environmental Surveillance at Hanford for CY-1977*. PNL-2614, Pacific Northwest Laboratory, Richland, Washington.

Houston, J.R., and P.J. Blumer. 1979. *Environmental Surveillance at Hanford for CY-1978*. PNL-2932, Pacific Northwest Laboratory, Richland, Washington.

Houston, J.R., and P.J. Blumer. 1980. *Environmental Surveillance at Hanford for CY-1979*. PNL-3283, Pacific Northwest Laboratory, Richland, Washington.

ICRP - International Commission on Radiological Protection. 1977. *Recommendations of the International Commission on Radiological Protection.* ICRP Publication 26, Pergamon Press, New York.

Jaquish, R.E., and R.W. Bryce. 1989. *Hanford Site Environmental Report for Calendar Year 1988.* PNL-6825, Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R.E., and R.W. Bryce. 1990. *Hanford Site Environmental Report for Calendar Year 1989.* PNL-7346, Pacific Northwest Laboratory, Richland, Washington.

Jaquish, R.E., and P.J. Mitchell. 1988. *Environmental Monitoring at Hanford for 1987.* PNL-6464, Pacific Northwest Laboratory, Richland, Washington.

Meehan, W.R. 1991. "Influences of Forest and Rangeland Management of Salmonid Fishes and Their Habitats." *American Fisheries Society Special Publication* 19:47-82.

Napier, B.A. 1991a. *Computational Model Design Specification for Phase I of the Hanford Environmental Dose Reconstruction Project.* PNL-7274 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Napier, B.A. 1991b. *Selection of Dominant Radionuclides for Phase I of the Hanford Environmental Dose Reconstruction Project.* PNL-7231 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Napier, B.A. 1993. *Determination of Key Radionuclides and Parameters Related to Dose from the Columbia River Pathway.* BN-SA-3768 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Napier, B.A., and A.J. Brothers. 1992. *Recommendations to the Technical Steering Panel Regarding Approach for Estimating Individual Radiation Doses Resulting from Releases of Radionuclides to the Columbia River, Volume 1: Recommendations.* PNWD-1977 HEDR, Vol. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Napier, B.A., J.C. Simpson, P.W. Eslinger, J.V. Ramsdell, Jr., M.E. Thiede, and W.H. Walters. 1994. *Validation of HEDR Models.* PNWD-2221 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

NCRP - National Council on Radiation Protection and Measurements. 1984. *Radiological Assessment: Predicting the Transport, Bioconcentration, and Uptake by Man of Radionuclides Released to the Environment.* NCRP Report No. 76, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

NRPB - National Radiological Protection Board. 1991. *Committed Equivalent Organ Doses and Committed Effective Doses from Intakes of Radionuclides.* NRPB-R245, National Radiological Protection Board, Didcot, United Kingdom.

Oregon Department of Fish & Wildlife and Washington Department of Fisheries. 1993. *Status Report, Columbia River Fish Runs and Fisheries 1938-92*. Washington Department of Fisheries, Olympia, Washington.

Parker, H.M., and W.D. Norwood. 1946a. *H.I. Section Report for October 1946*. HW-7-5301, General Electric Company, Hanford Works, Richland, Washington.

Parker, H.M., and W.D. Norwood. 1946b. *H.I. Section Report for November 1946*. HW-7-5428, General Electric Company, Hanford Works, Richland, Washington.

Phipps, A.W., G.M. Kendall, J.W. Stather, and T.P. Fell. 1991. *Committed Equivalnet Organ Doses and Committed Effective Doses from Intakes of Radionuclides*. NRPB-R245, National Radiological Protection Board, Chilton, Didcot, Oxfordshire, England.

PNL - Pacific Northwest Laboratory. 1987. *Environmental Monitoring at Hanford for 1986*. PNL-6120, Pacific Northwest Laboratory, Richland, Washington.

PNL - Pacific Northwest Laboratory. 1991. *Columbia River Pathway Report: Phase I of the Hanford Environmental Dose Reconstruction Project*. PNL-7411 HEDR Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

Poston, T.M., and D.C. Klopfer. 1988. "Concentration Factors Used in the Assessment of Radiation Dose to Consumers of Fish: A Review of 27 Radionuclides." *Health Physics* 55(5):751-766.

Shipler, D.B. 1993. *Integrated Task Plans for the Hanford Dose Reconstruction Project, June 1992 Through May 1994*. PNWD-2187 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Shipler, D.B., and B.A. Napier. 1992. *HEDR Modeling Approach*. PNWD-1983 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Shipler, D.B., and B.A. Napier. 1994. *HEDR Modeling Approach*. PNWD-1983 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Simpson, J.C., and J.V. Ramsdell, Jr. 1993. *Uncertainty and Sensitivity Analyses Plan*. PNWD-2124 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Snyder, S.F., W.T. Farris, B.A. Napier, T.A. Ikenberry, and R.O. Gilbert. 1994. *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, and CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)*. PNWD-2023 HEDR Rev. 1, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Soldat, J.K. 1968. *A Statistical Study of the Habits of Fishermen Utilizing the Columbia River Below Hanford*. BNWL-SA-1451, Battelle Northwest Laboratory, Richland, Washington.

Soldat, J.K. 1989. *Offsite Radiation Doses from Hanford Operations for the Years 1983 through 1987: A Comparison of Results Calculated by Two Methods.* PNL-7135, Pacific Northwest Laboratory, Richland, Washington.

Soldat, J.K., and T.H. Essig, eds. 1966. *Evaluation of Radiological Conditions in the Vicinity of Hanford for 1965.* BNWL-316, Battelle Northwest Laboratory, Richland, Washington.

Soldat, J.K., and J.F. Honstead. 1968. *Dietary Levels for Tri-City Elementary School Children.* BNWL-CC-1565 (February 26, 1968), Battelle Northwest Laboratory, Richland, Washington.

Soldat, J.K., K. R. Price, and W.D. McCormack. 1986. *Off-Site Radiation Doses Summarized from Hanford Environmental Monitoring Reports for the Years 1957-1984.* PNL-5795, Pacific Northwest Laboratory, Richland, Washington.

Spear, D.R., J.J. Fix, and P.J. Blumer. 1976. *Environmental Surveillance at Hanford for CY-1975.* BNWL-1979, Battelle Northwest Laboratory, Richland, Washington.

Sula, M.J., and P.J. Blumer. 1981. *Environmental Surveillance at Hanford for CY-1980.* PNL-3728, Pacific Northwest Laboratory, Richland, Washington.

Sula, M.J., J.M.V. Carlile, K.R. Price, and W.D. McCormack. 1983. *Environmental Surveillance at Hanford for CY-1982.* PNL-4657, Pacific Northwest Laboratory, Richland, Washington.

Sula, M.J., W.D. McCormack, R.L. Dirkes, K.R. Price, and P.A. Eddy. 1982. *Environmental Surveillance at Hanford for CY-1981.* PNL-4211, Pacific Northwest Laboratory, Richland, Washington.

Swanberg, F., Jr. 1962. "Quantitative Measurements of Some Gamma-Ray-Emitting Radionuclides in Nuclear Industrial Workers by Whole-Body Counting Techniques." *Health Physics* 8(1):67-71.

Thiede, M.E., D. J. Bates, E.I. Mart, and R. W. Hanf. 1994. *A Guide to Environmental Monitoring Data, 1945 through 1972.* PNWD-2226 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Vanderploeg, H.A., D.C. Parzyck, W.H. Wilcox, J.R. Keruher, and S.V. Kaye. 1975. *Bioaccumulation for Radionuclides in Freshwater Biota.* ORNL-5002, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Walters, W.H., R.L. Dirkes, and B.A. Napier. 1992. *Literature and Data Review for the Surface-Water Pathway: Columbia River and Adjacent Coastal Areas.* PNWD-2034 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Walters, W.H., M.C. Richmond, and B.G. Gilmore. 1994. *Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington, to Portland, Oregon, January 1950-January 1971.* PNWD-2225 HEDR, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Woodruff, R.K., and R.W. Hanf. 1991. *Hanford Site Environmental Report for Calendar Year 1990*. PNL-7930, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R.K., and R.W. Hanf. 1992. *Hanford Site Environmental Report for Calendar Year 1991*. PNL-8148, Pacific Northwest Laboratory, Richland, Washington.

Woodruff, R.K., and R.W. Hanf. 1993. *Hanford Site Environmental Report for Calendar Year 1992*. PNL-8682, Pacific Northwest Laboratory, Richland, Washington.

Appendix

Summary of Estimated Columbia River Doses

Appendix

Summary of Estimated Columbia River Doses

The doses to the three different representative individual types are presented in this appendix. The parameters that describe the representative individuals are presented in Section 3.4.3. The doses are presented as dose equivalent for red bone marrow and lower large intestine and as effective dose equivalent. All doses are in units of millirem for the effective dose equivalent. Both monthly estimates for each of 253 months and annual totals are provided for the period 1950 through 1971. For the red bone marrow and lower large intestine, doses estimated are presented as annual totals. Doses are calculated for twelve specific river segments. The segment names and approximate locations are as follows:

1. Ringold (from below reactor areas to north of Richland)
2. Richland (from north of Richland to above the Yakima River)
3. Kennewick/Pasco (from below the Yakima River to the Snake River)
4. Snake/Walla Walla rivers (from below the Snake River to near McNary Dam)
5. Umatilla/Boardman (from near McNary Dam to near Arlington, Oregon)
6. Arlington (Arlington, Oregon vicinity)
7. John Day Dam/Biggs (from below Arlington, Oregon, to near Biggs, Oregon)
8. Deschutes River (Deschutes River mouth vicinity)
9. The Dalles/Celilo (The Dalles/Celilo vicinity)
10. Klickitat River (Klickitat River mouth vicinity)
11. White Salmon/Cascade Locks (from White Salmon River to Bonneville Dam)
12. Lower River (from below Bonneville Dam to Columbia River mouth)

Table A.1. Maximum Representative Individual - Effective Dose Equivalent (millirem per month and millirem per year)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
JAN50	4.4	4.1	4.3	3	2.9	2.7	2.6	2.5	2.5	2.3	2.1	1.6
FEB50	4	3.7	3.8	2.4	2.3	2.2	2.1	2	2	1.9	1.8	1.4
MAR50	2.4	2.1	2.2	1.2	1.1	1	0.94	0.89	0.87	0.81	0.75	0.45
APR50	1.7	1.5	1.6	0.84	0.78	0.72	0.67	0.65	0.64	0.61	0.57	0.46
MAY50	0.91	0.83	0.92	0.58	0.53	0.5	0.48	0.46	0.46	0.44	0.41	0.32
JUN50	0.86	0.83	0.85	0.6	0.59	0.58	0.56	0.56	0.55	0.54	0.53	0.48
JUL50	0.99	0.95	0.99	0.85	0.81	0.78	0.76	0.75	0.74	0.73	0.7	0.61
AUG50	2.3	2.2	2.3	1.9	1.8	1.7	1.6	1.6	1.6	1.5	1.5	1.1
SEP50	3.8	3.6	3.7	2.9	2.7	2.6	2.5	2.4	2.4	2.3	2.2	1.7
OCT50	5	4.8	4.8	3.4	3.2	3.1	3	2.9	2.9	2.8	2.6	2.3
NOV50	6.9	6.6	6.4	4.3	4.2	4	3.9	3.7	3.7	3.5	3.4	2.9
DEC50	4.3	4.1	4	2.7	2.6	2.5	2.4	2.3	2.3	2.2	2.1	1.9
1950	38	35	36	25	23	22	22	21	20	20	19	15
JAN51	2.4	2.3	2.3	1.7	1.6	1.5	1.4	1.3	1.3	1.3	1.2	0.71
FEB51	2	1.9	1.9	1.2	1.1	1.1	1	0.95	0.94	0.9	0.86	0.59
MAR51	1.7	1.5	1.6	0.98	0.86	0.77	0.71	0.67	0.65	0.61	0.55	0.37
APR51	1.1	1	1.1	0.58	0.53	0.49	0.45	0.43	0.42	0.4	0.38	0.3
MAY51	0.42	0.38	0.43	0.29	0.27	0.25	0.24	0.24	0.23	0.22	0.21	0.18
JUN51	0.91	0.87	0.9	0.7	0.67	0.64	0.62	0.61	0.61	0.59	0.58	0.53
JUL51	1.1	1.1	1.1	1	0.95	0.91	0.88	0.87	0.86	0.84	0.82	0.74
AUG51	2.5	2.4	2.4	2	1.9	1.8	1.8	1.7	1.7	1.6	1.5	1.3
SEP51	4.8	4.6	4.7	3.7	3.5	3.3	3.2	3.1	3	2.9	2.7	2.3
OCT51	3.8	3.6	3.7	2.7	2.6	2.5	2.4	2.3	2.3	2.2	2.2	1.7
NOV51	5.4	5.2	5.3	3.6	3.5	3.4	3.3	3.1	3.1	3	2.9	2.1
DEC51	2.8	2.7	2.8	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.4	0.83
1951	29	28	28	20	19	18	18	17	17	16	15	12
JAN52	3.4	3.2	3.4	2.5	2.3	2.2	2.1	2	2	1.9	1.8	1.2
FEB52	2.5	2.3	2.4	1.5	1.4	1.4	1.3	1.2	1.2	1.2	1.1	0.7
MAR52	1.9	1.6	1.8	1.1	0.97	0.87	0.81	0.76	0.75	0.69	0.63	0.42
APR52	1.4	1.2	1.3	0.52	0.46	0.42	0.38	0.37	0.36	0.34	0.31	0.24
MAY52	0.57	0.52	0.59	0.32	0.29	0.27	0.25	0.25	0.24	0.23	0.22	0.18
JUN52	0.86	0.82	0.86	0.6	0.57	0.55	0.53	0.52	0.52	0.51	0.49	0.44
JUL52	1.6	1.5	1.6	1.3	1.2	1.1	1.1	1.1	1.1	1	0.97	0.84
AUG52	2.2	2.1	2.1	1.7	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.1
SEP52	4.3	4.2	4.2	3.1	2.9	2.7	2.6	2.5	2.5	2.3	2.2	1.7
OCT52	8	7.7	7.7	5.5	5.2	4.9	4.8	4.5	4.5	4.2	3.9	3
NOV52	9.2	8.9	8.8	6.4	6.1	5.9	5.7	5.4	5.3	5.1	4.9	5.4
DEC52	6.9	6.5	6.7	4.8	4.6	4.3	4.2	3.9	3.9	3.7	3.4	2.9
1952	43	40	41	29	28	26	25	24	24	23	21	18
JAN53	7.8	7.4	7.1	4.1	3.8	3.6	3.4	3.1	3.1	2.8	2.5	0.98
FEB53	4.5	4.3	4.2	2.7	2.5	2.4	2.2	2.1	2.1	2	1.9	1.1
MAR53	2.5	2.2	2.4	1.5	1.3	1.2	1.1	1	0.98	0.9	0.81	0.53
APR53	1.5	1.4	1.5	0.87	0.74	0.64	0.58	0.55	0.53	0.49	0.44	0.31
MAY53	1.6	1.5	1.6	0.83	0.72	0.63	0.57	0.55	0.53	0.5	0.45	0.32

Table A.1. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
JUN53	1.1	1	1.1	0.71	0.68	0.65	0.63	0.62	0.61	0.59	0.58	0.51
JUL53	1.6	1.5	1.5	1.2	1.1	1.1	1	1	0.99	0.97	0.92	0.8
AUG53	3.9	3.7	3.8	3.1	2.8	2.6	2.5	2.4	2.3	2.2	2.1	1.7
SEP53	4.8	4.5	4.6	3.7	3.4	3.1	3	2.8	2.8	2.6	2.5	2
OCT53	5.8	5.5	5.6	4.3	4	3.8	3.6	3.5	3.4	3.2	3.1	2.4
NOV53	10	9.5	9.1	6.4	4.7	4.6	4.5	4.2	4.2	4	3.9	2.7
DEC53	6	5.6	5.5	3.7	2.7	2.7	2.6	2.4	2.4	2.3	2.2	1.1
1953	51	48	48	33	29	27	26	24	24	23	21	14
JAN54	6.6	6.2	6	4.2	3.1	3	2.9	2.7	2.7	2.5	2.4	1.3
FEB54	6	5.6	5.4	3.2	2.7	2.7	2.6	2.4	2.4	2.3	2.2	1.4
MAR54	3.9	3.4	3.3	2	1.3	1.3	1.2	1.1	1.1	1.1	1	0.79
APR54	4.2	3.7	3.5	1.6	1.1	1.1	1	0.99	0.98	0.94	0.91	0.71
MAY54	1.6	1.4	1.5	0.86	0.68	0.65	0.63	0.62	0.61	0.6	0.57	0.52
JUN54	1.7	1.6	1.7	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1	0.95
JUL54	1.9	1.8	1.8	1.6	1.4	1.3	1.3	1.3	1.3	1.3	1.2	1.1
AUG54	3.8	3.6	3.7	3.1	2.5	2.4	2.4	2.3	2.3	2.2	2.2	1.9
SEP54	5.7	5.5	5.4	4.3	3.4	3.3	3.3	3.2	3.1	3.1	3	2.6
OCT54	7.9	7.5	7.3	5.3	4.3	4.2	4.2	4	4	3.9	3.7	3.1
NOV54	9.2	8.8	8.6	6.3	5.4	5.4	5.3	5.1	5	4.9	4.8	3.9
DEC54	5.8	5.5	5.6	4.1	3.4	3.3	3.3	3.1	3.1	3	2.9	2.2
1954	58	55	54	38	30	30	29	28	28	27	26	21
JAN55	6.3	5.9	5.9	4.3	3.2	3	3	2.8	2.8	2.7	2.5	1.7
FEB55	3.8	3.6	3.6	2.8	2.4	2.4	2.4	2.3	2.3	2.2	2.2	1.7
MAR55	4.4	3.9	3.8	2.7	1.7	1.6	1.6	1.5	1.5	1.4	1.4	0.98
APR55	4.4	3.9	3.7	2.1	1.4	1.4	1.3	1.3	1.3	1.2	1.2	0.85
MAY55	5.4	4.7	4.5	2	1.4	1.3	1.2	1.2	1.2	1.1	1.1	0.88
JUN55	3	2.9	2.9	2	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.6
JUL55	2	1.9	1.9	1.6	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1
AUG55	4.7	4.4	4.4	3.6	2.7	2.6	2.5	2.4	2.4	2.4	2.2	1.9
SEP55	6.3	6	5.8	4.5	3.5	3.5	3.4	3.3	3.3	3.2	3.1	2.8
OCT55	11	10	9.8	7	5.5	5.4	5.3	5	5	4.8	4.6	3.4
NOV55	13	12	12	8.4	7.2	7.1	7	6.7	6.7	6.5	6.4	4.3
DEC55	9.7	9.2	8.5	5.2	4.4	4.3	4.2	3.9	3.9	3.7	3.6	1.9
1955	74	69	66	46	37	36	35	33	33	32	31	23
JAN56	7.4	6.9	6.6	4.1	3.3	3.2	3	2.8	2.8	2.6	2.5	1.4
FEB56	7	6.6	6.5	4.3	3.6	3.5	3.4	3.2	3.2	3.1	3	2.2
MAR56	5.9	5.3	4.8	2.5	1.9	1.8	1.7	1.6	1.6	1.6	1.5	1.1
APR56	2.6	2.4	2.4	1.3	1.1	1	0.96	0.93	0.92	0.89	0.87	0.74
MAY56	1.3	1.2	1.3	0.81	0.67	0.64	0.61	0.6	0.59	0.57	0.55	0.49
JUN56	2	2	2	1.5	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.1
JUL56	3.3	3.2	3.3	2.7	2.3	2.2	2.2	2.1	2.1	2.1	2	1.8
AUG56	6.9	6.6	6.5	5.1	4	3.9	3.8	3.7	3.7	3.6	3.4	3
SEP56	9.4	9	8.6	6.4	5.1	5	5	4.7	4.7	4.6	4.5	3.9
OCT56	7.9	7.5	7.3	5.1	4.4	4.4	4.3	4.1	4.1	4.1	4	3.5
NOV56	13	12	12	8	6.4	6.2	6.1	5.7	5.7	5.5	5.4	4

Table A.1. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
DEC56	8	7.4	7	4.6	3.7	3.6	3.5	3.3	3.3	3.2	3.1	2.2
1956	75	70	68	46	38	37	36	34	34	33	32	26
JAN57	7.8	7.2	7.1	5.2	3.7	3.5	3.4	3.3	3.3	3.1	2.9	2.1
FEB57	7.5	6.8	6.7	4.3	3.3	3.3	3.2	3	3	2.9	2.8	2.1
MAR57	6.4	5.5	5	2	1.2	1.1	1	0.95	0.92	0.88	0.84	0.53
APR57	6	5.2	4.8	2.1	1.3	1.2	1.1	1.1	1	0.98	0.97	0.77
MAY57	1.8	1.6	1.7	0.94	0.72	0.69	0.65	0.63	0.61	0.59	0.56	0.5
JUN57	2.2	2.1	2.2	1.6	1.3	1.2	1.2	1.2	1.1	1.1	1.1	0.99
JUL57	5.5	5.3	5.3	4.2	3.3	3.2	3.1	3	2.9	2.8	2.7	2.5
AUG57	10	9.7	9.4	7.3	5.5	5.3	5.2	4.9	4.7	4.6	4.4	3.9
SEP57	14	13	13	8.8	6.9	6.7	6.6	6.2	6	5.9	5.7	4.9
OCT57	15	14	13	9.2	7.5	7.4	7.3	6.8	6.6	6.4	6.2	5.3
NOV57	20	19	18	13	11	10	10	9.5	9.3	9.1	8.8	7
DEC57	16	15	15	9.6	7.5	7.4	7.1	6.6	6.5	6.3	6.1	3.7
1957	110	110	100	68	53	51	50	47	46	45	43	34
JAN58	13	12	11	7.3	4.8	4.6	4.4	3.9	3.7	3.4	3.2	1.6
FEB58	12	11	10	5.6	4.6	4.6	4.3	3.9	3.9	3.7	3.6	2.2
MAR58	6	5.3	4.7	2.7	1.5	1.4	1.3	1.2	1.2	1.1	1.1	0.82
APR58	6.9	6.2	5.8	2.9	1.9	1.8	1.7	1.6	1.6	1.5	1.5	1.2
MAY58	3	2.8	2.8	1.5	1.1	1	0.97	0.93	0.91	0.87	0.84	0.76
JUN58	3	3	3	2.2	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.4
JUL58	8.1	7.8	7.7	6.2	4.7	4.5	4.3	4.1	4	3.9	3.7	3.2
AUG58	11	10	9.9	7.7	5.6	5.5	5.4	5.1	5	4.8	4.7	4.1
SEP58	10	9.9	9	6.2	4.7	4.6	4.6	4.3	4.2	4.1	4	3.5
OCT58	17	16	15	10	7.7	7.5	7.3	6.8	6.5	6.3	6	4.7
NOV58	20	19	17	11	9	8.8	8.7	8.1	8	7.8	7.6	5.4
DEC58	12	11	11	6.2	4.9	4.8	4.7	4.4	4.3	4.1	4	2.9
1958	120	110	110	70	52	51	49	46	45	43	42	32
JAN59	8.8	8.4	7.6	4.7	3.4	3.3	3.1	2.9	2.8	2.6	2.5	1.6
FEB59	9.5	8.9	8.2	5.3	4	3.9	3.8	3.5	3.4	3.3	3.1	2.1
MAR59	5.9	5.4	4.8	3	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.1
APR59	4.3	4	3.8	2.1	1.4	1.3	1.3	1.2	1.2	1.1	1.1	0.94
MAY59	2.1	2	2	1.3	0.9	0.84	0.8	0.77	0.74	0.72	0.69	0.6
JUN59	2.3	2.3	2.3	1.7	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.2
JUL59	3.1	3.1	3.1	2.7	2.2	2.1	2.1	2.1	2	2	1.9	1.8
AUG59	6.4	6.4	6	4.8	3.4	3.3	3.3	3.1	3	2.9	2.9	2.5
SEP59	9.5	9.4	9	7	5.8	5.7	5.6	5.4	5.3	5.2	5	4.4
OCT59	8.4	8.2	7.9	5.5	4.6	4.5	4.4	4.2	4.2	4.1	4	3.5
NOV59	17	17	16	11	9.7	9.4	9.2	8.8	8.6	8.3	8.1	6.5
DEC59	11	11	10	7.3	6.1	5.9	5.8	5.5	5.4	5.3	5.2	4.2
1959	89	86	81	57	45	43	42	40	39	38	37	30
JAN60	22	21	20	14	11	11	10	9.6	9.2	8.8	8.3	5.8
FEB60	9.3	8.9	8.4	5.6	5.2	5.2	5.2	5	5	5.1	5.1	3.8
MAR60	8.6	7.8	6.7	3.5	2.2	2.1	2	1.9	1.8	1.8	1.7	1.2

Table A.1. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
APR60	4.6	4.4	4.2	2.7	1.7	1.6	1.6	1.5	1.4	1.4	1.3	1.1
MAY60	3.6	3.6	3.4	2.1	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1
JUN60	4.6	4.6	4.6	3.3	2.9	2.8	2.7	2.7	2.7	2.6	2.6	2.3
JUL60	4.9	4.9	4.8	4.2	3.5	3.4	3.4	3.3	3.2	3.2	3.1	2.9
AUG60	8.2	8	7.4	5.7	4	3.9	3.8	3.7	3.6	3.5	3.4	3
SEP60	13	13	12	8.6	6.6	6.4	6.3	5.9	5.8	5.6	5.3	4.4
OCT60	14	14	13	9.2	7.3	7.1	7	6.5	6.3	6.1	6	5
NOV60	24	23	21	14	11	11	11	10	9.8	9.4	9.1	5.9
DEC60	19	18	17	11	8.8	8.5	8.3	7.6	7.4	7.1	6.8	4.4
1960	140	130	120	85	66	64	63	59	58	56	54	41
JAN61	23	22	20	13	9.7	9.3	9.1	8.3	7.9	7.4	6.9	4.3
FEB61	13	12	12	7.3	6.6	6.6	6.4	6.1	6	5.9	5.7	3.9
MAR61	9.4	8.9	7.9	4.9	3.5	3.4	3.2	3	3	2.8	2.7	1.8
APR61	8.7	8.3	7.8	4.9	3.9	3.8	3.7	3.5	3.4	3.4	3.3	2.7
MAY61	3.4	3.4	3.2	2.1	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5
JUN61	3.4	3.4	3.4	2.8	2.6	2.5	2.5	2.4	2.4	2.4	2.3	2.2
JUL61	3.7	3.7	3.6	3.1	2.5	2.4	2.4	2.3	2.3	2.3	2.2	2.1
AUG61	8.8	8.7	8.3	6.8	5.5	5.3	5.3	5	4.9	4.7	4.5	3.8
SEP61	12	12	11	8	6.6	6.5	6.4	6	5.9	5.7	5.6	5
OCT61	11	11	10	7.1	6.2	6.2	6.1	5.7	5.7	5.6	5.5	5.1
NOV61	18	17	16	11	9.2	8.9	8.7	8	7.8	7.5	7.2	5.2
DEC61	8.2	8	7.4	4.9	4.3	4.3	4.2	3.9	3.9	3.8	3.8	2.5
1961	120	120	110	77	62	61	60	56	55	53	51	40
JAN62	13	13	12	7.7	5.8	5.6	5.5	5.1	4.9	4.7	4.5	3.3
FEB62	8.9	8.7	8.1	5.2	4.6	4.6	4.5	4.2	4.2	4.2	4.1	3.4
MAR62	8.2	7.5	6.5	3.6	2.6	2.5	2.4	2.3	2.2	2.2	2.1	1.5
APR62	8.6	8.2	7.6	3.8	2.9	2.9	2.7	2.6	2.6	2.4	2.5	2
MAY62	3.2	3.2	3.2	1.9	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.2
JUN62	5.1	5.2	5.1	3.7	3.3	3.2	3.2	3.1	3.1	3	3	2.8
JUL62	7.4	7.4	7.4	6.2	5.5	5.4	5.3	5.2	5.1	5	4.9	4.5
AUG62	12	12	11	9.2	7.8	7.6	7.6	7.2	7.1	7	6.8	6.1
SEP62	22	22	21	16	13	13	13	12	12	11	11	9.3
OCT62	11	11	11	7.3	7.7	7.8	7.9	7.6	7.8	7.8	7.9	7
NOV62	14	14	13	8.7	7.7	7.6	7.5	7	6.9	6.7	6.6	4.8
DEC62	9.9	9.7	9.1	6	5.2	5.1	5	4.7	4.6	4.5	4.4	3.2
1962	120	120	120	79	68	67	66	62	61	60	59	49
JAN63	6.5	6.4	6	4.4	3.4	3.3	3.2	3	2.9	2.8	2.7	2.2
FEB63	5.2	5.1	4.7	2.8	2.6	2.5	2.4	2.3	2.3	2.2	2.2	1.7
MAR63	4.5	4.2	3.5	2	1.1	1	0.98	0.91	0.88	0.85	0.82	0.65
APR63	4.1	4	3.6	2.1	1.4	1.3	1.2	1.2	1.2	1.1	1.1	0.77
MAY63	2.1	2.1	2	1	0.71	0.68	0.65	0.62	0.61	0.6	0.59	0.5
JUN63	2.4	2.4	2.3	1.6	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1
JUL63	3	3	2.9	2.3	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.2
AUG63	5	4.9	4.5	3.5	2.4	2.4	2.3	2.2	2.1	2.1	2	1.7
SEP63	6.9	7.3	6	4.1	3	2.9	2.9	2.7	2.6	2.5	2.4	2

Table A.1. (contd)

Month/Year	1	2	3	4	5	Location 6	7	8	9	10	11	12
OCT63	8.7	9.2	7.7	5.3	3.9	3.8	3.7	3.4	3.2	3.1	2.9	2.8
NOV63	12	13	11	7	5.5	5.4	5.3	4.8	4.7	4.5	4.4	4
DEC63	7.1	7.7	6.3	4	3.1	3	2.9	2.7	2.6	2.5	2.4	1.7
1963	68	72	60	40	30	29	28	26	26	25	24	20
JAN64	8.2	8.6	7	4.4	2.9	2.8	2.7	2.5	2.3	2.2	2	0.93
FEB64	6.3	6.7	5.7	3.9	3.1	3	2.9	2.8	2.7	2.6	2.5	1.8
MAR64	5.1	5.4	3.9	2.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	0.76
APR64	5.4	5.9	4.4	1.9	1.3	1.3	1.2	1.1	1.1	1.1	1.1	0.89
MAY64	3.3	3.8	3.1	1.5	1	0.98	0.94	0.91	0.88	0.85	0.82	0.71
JUN64	2.1	2.3	2.1	1.4	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1
JUL64	1.8	2	1.8	1.4	1	0.99	0.95	0.93	0.91	0.88	0.85	0.77
AUG64	4.2	4.5	4	3	2.2	2.1	2.1	2	1.9	1.9	1.8	1.6
SEP64	8.1	8.6	7.2	4.9	3.7	3.6	3.6	3.4	3.3	3.1	3	3
OCT64	4.7	5.1	4.4	3.2	2.6	2.6	2.5	2.5	2.4	2.4	2.4	2.2
NOV64	11	12	9.9	6.7	5.1	5	4.9	4.6	4.4	4.1	3.9	2.8
DEC64	6.5	7.1	5.6	3.1	2.4	2.4	2.3	2.1	2.1	2	2	1.1
1964	67	72	59	38	28	27	26	25	24	23	22	18
JAN65	6.4	6.8	5.4	3.1	2.4	2.4	2.2	2.1	2	1.9	1.8	1.1
FEB65	4.3	4.7	3.8	1.9	1.6	1.6	1.5	1.4	1.4	1.4	1.3	1.1
MAR65	3.4	3.8	2.9	1.5	1	0.96	0.92	0.88	0.85	0.83	0.79	0.67
APR65	3.1	3.4	2.7	1.3	0.93	0.9	0.86	0.82	0.81	0.79	0.77	0.7
MAY65	1.5	1.8	1.5	0.87	0.6	0.55	0.52	0.5	0.49	0.47	0.44	0.39
JUN65	2.1	2.3	2.1	1.4	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1
JUL65	2	2.2	2	1.5	1.1	1.1	1.1	1	1	0.98	0.95	0.88
AUG65	3.5	3.7	3.2	2.4	1.7	1.6	1.6	1.5	1.5	1.4	1.4	1.2
SEP65	5.9	6.2	5.1	3.4	2.4	2.3	2.3	2.2	2.1	2	1.9	1.6
OCT65	8.2	8.3	6.7	4.1	3	2.9	2.8	2.6	2.5	2.4	2.3	1.9
NOV65	8.2	8.6	7.3	4.9	3.8	3.7	3.7	3.5	3.3	3.2	3	2.5
DEC65	4.7	5	4.2	2.8	2.2	2.1	2.1	1.9	1.9	1.8	1.7	1.3
1965	53	57	47	29	22	21	21	20	19	18	17	14
JAN66	4.5	4.8	4	2.5	1.8	1.7	1.7	1.5	1.5	1.4	1.3	0.8
FEB66	3	3.3	2.7	1.8	1.4	1.4	1.4	1.3	1.3	1.3	1.2	0.98
MAR66	3	3.1	2.3	1.3	0.69	0.66	0.64	0.59	0.58	0.55	0.53	0.36
APR66	2.7	2.9	2.1	1	0.65	0.63	0.61	0.58	0.56	0.54	0.52	0.42
MAY66	1.4	1.6	1.3	0.83	0.52	0.48	0.47	0.45	0.43	0.42	0.41	0.36
JUN66	1.4	1.6	1.4	1.1	0.9	0.87	0.85	0.83	0.81	0.8	0.79	0.74
JUL66	0.4	0.45	0.41	0.36	0.3	0.3	0.3	0.29	0.29	0.29	0.29	0.29
AUG66	0.82	0.93	0.75	0.58	0.37	0.36	0.35	0.33	0.32	0.31	0.3	0.25
SEP66	6.6	6.9	5.8	4.2	2.9	2.7	2.7	2.4	2.3	2.2	2	1.6
OCT66	7.1	7.4	6.3	4.5	3.8	3.7	3.6	3.4	3.3	3.2	3	3
NOV66	7.2	7.5	6.6	4.7	4	4	3.9	3.7	3.7	3.6	3.5	2.6
DEC66	4.5	4.9	4	2.7	2.3	2.2	2.2	2	2	1.9	1.9	1.2
1966	43	45	38	26	20	19	19	18	17	16	16	13
JAN67	5.1	5.4	4.6	3	2.3	2.2	2.2	2	1.9	1.8	1.7	1

Table A.1. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
FEB67	4.8	5.1	4.2	2.7	2.3	2.2	2.2	2	2	2	1.9	1.4
MAR67	2.8	3.1	2.5	1.6	1.1	1.1	1.1	1	1	0.99	0.96	0.78
APR67	3.6	3.9	3	1.8	1.2	1.2	1.2	1.1	1.1	1.1	1.1	0.88
MAY67	2.5	2.8	2.1	1.1	0.76	0.73	0.7	0.68	0.67	0.66	0.65	0.6
JUN67	1.7	1.8	1.7	1.2	1.1	1.1	1	1	1	1	0.97	0.92
JUL67	2.1	2.2	2.1	1.8	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.1
AUG67	4.3	4.5	4	3.2	2.5	2.4	2.3	2.2	2.1	2.1	2	1.8
SEP67	6.1	6.4	5.5	4.2	3.2	3.1	3.1	2.9	2.9	2.7	2.6	2.3
OCT67	5.9	6.2	5.3	3.6	2.9	2.9	2.9	2.7	2.7	2.6	2.5	2
NOV67	6.1	6.3	5.6	3.8	3.3	3.2	3.2	3	2.9	2.8	2.7	2.1
DEC67	3.4	3.7	3.1	2.2	1.8	1.8	1.8	1.7	1.6	1.6	1.5	1.1
1967	49	51	44	30	24	23	23	22	21	21	20	16
JAN68	3.1	3.3	2.7	1.8	1.3	1.3	1.3	1.2	1.1	1.1	1	0.65
FEB68	4.7	4.9	3.7	2.1	1.6	1.5	1.5	1.4	1.4	1.4	1.3	0.9
MAR68	2.3	2.4	1.8	1.1	0.66	0.63	0.6	0.57	0.55	0.53	0.5	0.39
APR68	2.3	2.5	2	1.2	0.69	0.56	0.54	0.52	0.52	0.51	0.5	0.46
MAY68	1.5	1.7	1.4	0.78	0.55	0.49	0.47	0.45	0.45	0.44	0.43	0.39
JUN68	1.2	1.3	1.2	0.84	0.74	0.72	0.72	0.71	0.71	0.7	0.7	0.67
JUL68	1.2	1.3	1.2	1	0.74	0.64	0.59	0.58	0.57	0.56	0.54	0.5
AUG68	3.4	3.6	3.2	2.4	1.8	1.5	1.3	1.2	1.2	1.2	1.1	0.9
SEP68	3.6	3.8	3.3	2.5	1.9	1.7	1.6	1.5	1.5	1.4	1.4	1.2
OCT68	3.9	4.1	3.4	2.3	1.8	1.5	1.3	1.3	1.2	1.2	1.2	0.91
NOV68	4.6	4.8	4.1	2.6	2.3	2	1.8	1.7	1.6	1.6	1.5	1
DEC68	2.3	2.5	2.1	1.4	1.2	1	0.93	0.88	0.88	0.86	0.84	0.52
1968	34	36	30	20	15	14	13	12	12	11	11	8.5
JAN69	2.1	2.2	1.9	1.2	0.94	0.78	0.67	0.63	0.61	0.6	0.57	0.42
FEB69	2	2.1	1.9	1.3	1	0.9	0.83	0.79	0.78	0.76	0.74	0.57
MAR69	1.8	1.9	1.5	0.82	0.51	0.43	0.39	0.37	0.36	0.36	0.35	0.3
APR69	1	1.1	0.94	0.55	0.37	0.3	0.27	0.26	0.26	0.26	0.25	0.23
MAY69	0.63	0.71	0.58	0.35	0.22	0.17	0.15	0.15	0.14	0.14	0.14	0.12
JUN69	1.2	1.3	1.1	0.81	0.62	0.54	0.49	0.48	0.47	0.46	0.45	0.4
JUL69	1.5	1.6	1.4	1.1	0.83	0.67	0.61	0.58	0.57	0.56	0.54	0.48
AUG69	3.1	3.2	2.8	2.2	1.6	1.3	1.2	1.1	1.1	1	0.98	0.81
SEP69	3	3.1	2.6	1.9	1.5	1.3	1.3	1.2	1.2	1.1	1.1	1
OCT69	2.5	2.6	2.3	1.6	1.3	1.1	1	0.95	0.93	0.91	0.88	0.75
NOV69	2.1	2.1	1.9	1.4	1.3	1.2	1.1	1.1	1.1	1	1	0.92
DEC69	1.4	1.5	1.3	1	0.79	0.7	0.64	0.61	0.6	0.59	0.57	0.39
1969	22	24	20	14	11	9.4	8.6	8.2	8	7.8	7.6	6.4
JAN70	1.2	1.4	1.1	0.66	0.45	0.36	0.3	0.28	0.27	0.26	0.24	0.15
FEB70	0.051	0.075	0.084	0.056	0.088	0.14	0.14	0.14	0.14	0.15	0.15	0.11
MAR70	0.2	0.23	0.18	0.11	0.078	0.061	0.05	0.046	0.044	0.042	0.04	0.031
APR70	0.85	0.94	0.74	0.45	0.29	0.24	0.21	0.2	0.19	0.18	0.18	0.14
MAY70	0.6	0.69	0.55	0.27	0.21	0.2	0.2	0.19	0.19	0.19	0.19	0.18
JUN70	0.64	0.7	0.63	0.34	0.29	0.27	0.26	0.25	0.25	0.25	0.24	0.23
JUL70	1.7	1.8	1.6	1.1	0.85	0.69	0.61	0.58	0.57	0.55	0.53	0.46

Table A.1. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
AUG70	1.3	1.4	1.2	0.97	0.77	0.72	0.69	0.66	0.66	0.65	0.64	0.59
SEP70	3.1	3.2	2.8	2	1.4	1.1	0.98	0.91	0.88	0.85	0.81	0.7
OCT70	3	3.2	2.7	1.9	1.6	1.4	1.3	1.2	1.2	1.2	1.1	0.97
NOV70	3.6	3.7	3.3	2.2	1.9	1.7	1.6	1.5	1.5	1.4	1.4	1.1
DEC70	2	2.1	1.8	1.2	0.99	0.91	0.85	0.79	0.78	0.77	0.75	0.5
1970	18	19	17	11	9	7.8	7.2	6.7	6.6	6.5	6.3	5.1
JAN71	1.9	1.9	1.6	0.8	0.62	0.45	0.37	0.33	0.32	0.3	0.27	0.14

Table A.2. Maximum Representative Individual - Red Bone Marrow Equivalent Dose (millirem per year)

	Location											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1950	66	65	62	43	42	41	40	38	38	36	35	29
1951	52	52	50	36	35	34	33	32	32	31	29	22
1952	94	93	90	65	63	60	59	56	55	53	50	44
1953	110	110	100	71	63	61	59	56	55	53	50	34
1954	100	100	95	70	60	59	57	55	54	53	51	40
1955	120	120	110	79	68	66	65	62	62	60	58	42
1956	120	120	110	79	67	66	64	61	61	59	57	44
1957	200	200	190	130	110	110	100	97	94	91	87	66
1958	240	240	220	150	120	120	120	110	110	100	98	73
1959	180	180	170	120	100	100	98	93	91	88	85	68
1960	270	270	250	180	140	140	140	130	120	120	110	83
1961	240	240	220	160	130	130	120	120	110	110	100	78
1962	220	220	200	140	120	120	120	110	110	110	100	86
1963	150	150	130	93	75	73	70	66	63	61	58	47
1964	140	140	130	84	68	66	64	61	59	56	53	41
1965	120	120	110	71	59	57	56	52	51	49	46	37
1966	91	93	83	59	47	46	45	42	41	39	37	29
1967	100	110	95	68	58	56	55	52	51	49	47	37
1968	77	79	70	48	40	35	32	30	30	29	27	21
1969	47	49	44	33	28	23	21	20	19	19	18	15
1970	38	39	36	25	21	17	15	14	14	13	13	10
1971	4.1	4.1	3.5	1.8	1.4	0.98	0.78	0.69	0.66	0.62	0.56	0.29

Table A.3. Maximum Representative Individual - Lower Large Intestine Equivalent Dose (millirem per year)

	Location											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1950	130	110	130	85	77	69	64	61	60	55	50	35
1951	100	86	100	73	66	59	56	53	52	48	43	28
1952	160	130	160	110	98	88	83	79	77	70	63	48
1953	220	180	200	140	110	96	89	84	82	74	66	39
1954	220	180	190	130	78	74	71	68	67	63	60	44
1955	280	230	240	150	90	85	81	78	76	73	68	47
1956	260	220	230	150	89	84	81	77	76	72	68	50
1957	430	350	360	220	130	120	120	110	110	100	95	70
1958	490	410	400	250	140	140	130	120	110	110	100	74
1959	320	280	270	180	120	110	110	100	98	94	90	70
1960	460	400	390	260	160	150	150	140	130	130	120	86
1961	380	330	320	220	140	140	130	120	120	110	110	80
1962	330	290	290	190	140	130	130	120	120	110	110	90
1963	250	260	210	140	83	79	76	70	67	63	60	48
1964	250	260	210	130	78	74	71	66	63	60	56	42
1965	210	210	170	100	67	63	60	56	54	51	48	37
1966	150	150	120	80	51	48	47	43	42	40	37	29
1967	170	170	140	95	63	61	59	55	53	51	48	38
1968	130	130	110	70	44	36	33	31	30	29	27	20
1969	83	85	72	49	32	24	21	20	19	19	18	15
1970	60	62	52	34	22	17	15	14	14	13	13	10
1971	5.1	5.4	4.2	2.1	1.5	0.98	0.77	0.69	0.66	0.62	0.56	0.28

Table A.4. Typical Representative Individual - Effective Dose Equivalent (millirem per month and millirem per year)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
JAN50	0.34	0.17	0.42	0.36	0.33	0.3	0.29	0.28	0.28	0.26	0.24	0.21
FEB50	0.16	0	0.24	0.16	0.14	0.12	0.11	0.1	0.098	0.086	0.074	0.041
MAR50	0.15	0	0.22	0.13	0.11	0.099	0.089	0.084	0.081	0.073	0.062	0.03
APR50	0.11	0	0.16	0.091	0.08	0.072	0.065	0.062	0.06	0.056	0.049	0.033
MAY50	0.06	0.0055	0.095	0.064	0.057	0.052	0.048	0.046	0.045	0.043	0.038	0.026
JUN50	0.027	0.0057	0.042	0.032	0.029	0.027	0.025	0.025	0.024	0.023	0.021	0.017
JUL50	0.031	0.0066	0.049	0.045	0.04	0.036	0.033	0.033	0.031	0.03	0.027	0.02
AUG50	0.069	0.013	0.11	0.097	0.083	0.071	0.065	0.063	0.061	0.056	0.048	0.029
SEP50	0.14	0.047	0.2	0.17	0.15	0.13	0.12	0.12	0.11	0.1	0.091	0.064
OCT50	0.16	0	0.23	0.17	0.15	0.13	0.12	0.11	0.11	0.095	0.08	0.048
NOV50	0.16	0	0.24	0.17	0.15	0.13	0.12	0.11	0.11	0.095	0.081	0.051
DEC50	0.17	0	0.24	0.17	0.15	0.13	0.12	0.11	0.11	0.096	0.082	0.054
1950	1.6	0.25	2.2	1.7	1.5	1.3	1.2	1.2	1.1	1	0.9	0.62
JAN51	0.23	0.13	0.27	0.24	0.22	0.21	0.2	0.19	0.19	0.18	0.17	0.15
FEB51	0.091	0	0.13	0.089	0.077	0.067	0.06	0.056	0.054	0.048	0.041	0.022
MAR51	0.11	0	0.17	0.11	0.095	0.081	0.073	0.069	0.066	0.059	0.051	0.027
APR51	0.079	0	0.12	0.067	0.06	0.053	0.048	0.046	0.044	0.041	0.036	0.025
MAY51	0.032	0.0034	0.05	0.036	0.032	0.03	0.028	0.027	0.026	0.025	0.022	0.017
JUN51	0.031	0.0073	0.049	0.04	0.036	0.032	0.03	0.029	0.028	0.027	0.024	0.019
JUL51	0.041	0.0086	0.064	0.06	0.052	0.046	0.043	0.042	0.04	0.038	0.034	0.026
AUG51	0.086	0.021	0.13	0.12	0.1	0.083	0.076	0.074	0.071	0.063	0.053	0.034
SEP51	0.18	0.057	0.26	0.22	0.2	0.17	0.16	0.15	0.14	0.13	0.11	0.075
OCT51	0.12	0	0.19	0.14	0.12	0.11	0.099	0.094	0.091	0.08	0.068	0.038
NOV51	0.15	0	0.23	0.17	0.15	0.12	0.11	0.11	0.1	0.09	0.075	0.036
DEC51	0.14	0	0.21	0.15	0.13	0.11	0.097	0.092	0.089	0.077	0.064	0.025
1951	1.3	0.23	1.9	1.4	1.3	1.1	1	0.98	0.95	0.86	0.75	0.49
JAN52	0.26	0.1	0.34	0.28	0.26	0.23	0.22	0.21	0.21	0.2	0.18	0.14
FEB52	0.11	0	0.17	0.11	0.097	0.083	0.075	0.071	0.068	0.059	0.05	0.022
MAR52	0.13	0	0.19	0.13	0.11	0.094	0.085	0.081	0.077	0.069	0.058	0.03
APR52	0.1	0	0.16	0.064	0.056	0.05	0.044	0.042	0.041	0.038	0.033	0.022
MAY52	0.043	0.0061	0.069	0.04	0.036	0.032	0.029	0.029	0.028	0.026	0.024	0.018
JUN52	0.034	0.0095	0.052	0.039	0.034	0.03	0.027	0.027	0.026	0.024	0.022	0.016
JUL52	0.055	0.016	0.086	0.074	0.063	0.053	0.049	0.048	0.046	0.042	0.037	0.025
AUG52	0.084	0.025	0.13	0.11	0.092	0.076	0.069	0.066	0.063	0.055	0.046	0.028
SEP52	0.18	0.076	0.24	0.19	0.16	0.14	0.12	0.12	0.12	0.1	0.085	0.058
OCT52	0.19	0	0.28	0.22	0.18	0.15	0.14	0.13	0.12	0.1	0.082	0.045
NOV52	0.18	0	0.27	0.21	0.18	0.15	0.13	0.12	0.12	0.1	0.081	0.062
DEC52	0.24	0	0.37	0.28	0.23	0.19	0.17	0.16	0.16	0.13	0.1	0.059
1952	1.6	0.24	2.3	1.7	1.5	1.3	1.2	1.1	1.1	0.94	0.8	0.52
JAN53	0.35	0.099	0.44	0.31	0.27	0.24	0.22	0.21	0.21	0.19	0.17	0.12
FEB53	0.16	0	0.24	0.16	0.14	0.12	0.1	0.096	0.092	0.081	0.067	0.029
MAR53	0.15	0	0.23	0.16	0.14	0.12	0.1	0.098	0.095	0.084	0.07	0.036
APR53	0.11	0	0.16	0.1	0.087	0.074	0.066	0.063	0.06	0.054	0.046	0.026
MAY53	0.12	0.02	0.17	0.099	0.084	0.072	0.064	0.062	0.059	0.054	0.047	0.029

Table A.4. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
JUN53	0.037	0.012	0.056	0.04	0.034	0.031	0.028	0.027	0.026	0.024	0.022	0.016
JUL53	0.053	0.015	0.081	0.069	0.058	0.05	0.046	0.045	0.043	0.04	0.035	0.025
AUG53	0.13	0.038	0.2	0.17	0.14	0.11	0.1	0.098	0.094	0.083	0.068	0.04
SEP53	0.21	0.072	0.29	0.25	0.21	0.18	0.16	0.16	0.15	0.13	0.11	0.073
OCT53	0.2	0	0.3	0.25	0.21	0.17	0.15	0.15	0.14	0.12	0.097	0.05
NOV53	0.24	0	0.3	0.21	0.072	0.065	0.061	0.058	0.056	0.051	0.046	0.028
DEC53	0.25	0	0.3	0.2	0.068	0.062	0.058	0.053	0.052	0.047	0.042	0.019
1953	2	0.26	2.8	2	1.5	1.3	1.2	1.1	1.1	0.95	0.82	0.49
JAN54	0.5	0.26	0.57	0.47	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.28
FEB54	0.24	0	0.31	0.18	0.087	0.08	0.075	0.069	0.068	0.063	0.058	0.031
MAR54	0.23	0	0.3	0.19	0.089	0.082	0.076	0.071	0.07	0.064	0.059	0.039
APR54	0.25	0	0.32	0.15	0.082	0.075	0.069	0.066	0.064	0.06	0.055	0.037
MAY54	0.098	0.013	0.15	0.089	0.061	0.056	0.053	0.052	0.05	0.049	0.044	0.035
JUN54	0.056	0.017	0.087	0.072	0.052	0.048	0.044	0.044	0.042	0.04	0.037	0.03
JUL54	0.057	0.019	0.087	0.079	0.054	0.049	0.045	0.045	0.043	0.041	0.038	0.031
AUG54	0.11	0.034	0.16	0.14	0.075	0.067	0.063	0.062	0.06	0.057	0.052	0.039
SEP54	0.2	0.074	0.26	0.21	0.11	0.11	0.1	0.099	0.098	0.093	0.087	0.072
OCT54	0.22	0	0.3	0.22	0.096	0.088	0.084	0.08	0.078	0.073	0.067	0.05
NOV54	0.19	0	0.26	0.19	0.089	0.083	0.08	0.076	0.074	0.07	0.065	0.047
DEC54	0.21	0	0.28	0.2	0.089	0.083	0.08	0.075	0.074	0.069	0.064	0.043
1954	2.4	0.41	3.1	2.2	1.2	1.1	1.1	1.1	1	0.99	0.93	0.73
JAN55	0.54	0.31	0.61	0.52	0.39	0.38	0.38	0.38	0.38	0.37	0.36	0.34
FEB55	0.15	0	0.2	0.15	0.073	0.068	0.066	0.062	0.061	0.058	0.054	0.038
MAR55	0.23	0	0.32	0.24	0.11	0.098	0.093	0.089	0.087	0.082	0.074	0.047
APR55	0.22	0	0.3	0.18	0.093	0.086	0.081	0.078	0.076	0.072	0.067	0.042
MAY55	0.28	0.025	0.38	0.18	0.1	0.093	0.086	0.083	0.081	0.077	0.07	0.05
JUN55	0.087	0.022	0.13	0.097	0.07	0.065	0.061	0.06	0.058	0.056	0.052	0.042
JUL55	0.066	0.025	0.1	0.091	0.057	0.051	0.048	0.047	0.045	0.043	0.04	0.031
AUG55	0.15	0.043	0.21	0.18	0.083	0.075	0.07	0.068	0.066	0.062	0.056	0.041
SEP55	0.25	0.092	0.31	0.24	0.11	0.11	0.1	0.1	0.1	0.095	0.089	0.075
OCT55	0.28	0	0.36	0.26	0.12	0.11	0.1	0.097	0.096	0.089	0.081	0.055
NOV55	0.27	0	0.35	0.25	0.12	0.11	0.11	0.1	0.1	0.096	0.089	0.054
DEC55	0.35	0	0.43	0.26	0.13	0.12	0.11	0.1	0.1	0.093	0.086	0.04
1955	2.9	0.52	3.7	2.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	0.86
JAN56	0.65	0.38	0.73	0.59	0.47	0.46	0.46	0.45	0.45	0.44	0.43	0.4
FEB56	0.27	0	0.36	0.24	0.12	0.11	0.1	0.095	0.094	0.087	0.081	0.052
MAR56	0.3	0	0.38	0.21	0.12	0.11	0.1	0.097	0.095	0.089	0.083	0.052
APR56	0.13	0	0.19	0.11	0.079	0.073	0.067	0.065	0.064	0.061	0.057	0.044
MAY56	0.072	0.013	0.11	0.075	0.057	0.053	0.049	0.048	0.046	0.044	0.041	0.034
JUN56	0.064	0.028	0.095	0.076	0.054	0.05	0.046	0.045	0.044	0.042	0.038	0.031
JUL56	0.11	0.046	0.16	0.14	0.082	0.074	0.069	0.068	0.066	0.062	0.057	0.045
AUG56	0.23	0.083	0.31	0.24	0.11	0.1	0.098	0.094	0.092	0.087	0.079	0.061
SEP56	0.34	0.13	0.42	0.31	0.15	0.14	0.14	0.13	0.13	0.12	0.12	0.097
OCT56	0.22	0	0.29	0.2	0.099	0.093	0.09	0.085	0.084	0.08	0.075	0.06
NOV56	0.27	0	0.35	0.23	0.1	0.094	0.089	0.084	0.083	0.077	0.071	0.049

Table A.4. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
DEC56	0.39	0	0.46	0.29	0.11	0.1	0.095	0.09	0.088	0.081	0.072	0.043
1956	3.1	0.67	3.9	2.7	1.6	1.5	1.4	1.4	1.3	1.3	1.2	0.97
JAN57	0.65	0.32	0.73	0.61	0.42	0.41	0.4	0.4	0.39	0.39	0.38	0.35
FEB57	0.35	0	0.44	0.28	0.11	0.1	0.094	0.089	0.086	0.079	0.071	0.043
MAR57	0.42	0	0.5	0.22	0.094	0.084	0.076	0.067	0.061	0.056	0.051	0.028
APR57	0.35	0	0.44	0.2	0.11	0.095	0.085	0.077	0.072	0.066	0.062	0.043
MAY57	0.11	0.023	0.16	0.097	0.069	0.064	0.059	0.057	0.054	0.051	0.047	0.038
JUN57	0.08	0.038	0.12	0.089	0.054	0.048	0.044	0.042	0.039	0.037	0.034	0.026
JUL57	0.19	0.088	0.25	0.2	0.095	0.085	0.08	0.075	0.07	0.065	0.06	0.048
AUG57	0.33	0.12	0.42	0.32	0.13	0.11	0.11	0.099	0.091	0.085	0.078	0.062
SEP57	0.49	0.19	0.57	0.38	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.1
OCT57	0.33	0	0.42	0.28	0.14	0.13	0.12	0.11	0.11	0.1	0.098	0.081
NOV57	0.37	0	0.46	0.31	0.14	0.14	0.13	0.12	0.11	0.11	0.11	0.083
DEC57	0.52	0	0.62	0.39	0.16	0.15	0.14	0.13	0.12	0.12	0.11	0.069
1957	4.2	0.78	5.1	3.4	1.7	1.6	1.5	1.4	1.3	1.3	1.2	0.98
JAN58	0.79	0.32	0.86	0.65	0.42	0.41	0.4	0.39	0.38	0.38	0.37	0.34
FEB58	0.39	0	0.48	0.26	0.12	0.11	0.1	0.089	0.085	0.079	0.074	0.041
MAR58	0.29	0	0.37	0.23	0.1	0.093	0.085	0.076	0.071	0.065	0.06	0.041
APR58	0.29	0	0.39	0.21	0.12	0.11	0.1	0.094	0.089	0.084	0.079	0.058
MAY58	0.15	0.036	0.21	0.12	0.08	0.074	0.068	0.064	0.061	0.058	0.054	0.045
JUN58	0.094	0.06	0.13	0.1	0.056	0.049	0.044	0.042	0.039	0.037	0.033	0.026
JUL58	0.19	0.098	0.26	0.2	0.088	0.078	0.073	0.067	0.062	0.058	0.053	0.041
AUG58	0.33	0.13	0.41	0.3	0.11	0.1	0.096	0.087	0.08	0.075	0.07	0.055
SEP58	0.41	0.2	0.44	0.29	0.11	0.1	0.1	0.093	0.088	0.085	0.082	0.073
OCT58	0.39	0	0.49	0.33	0.14	0.13	0.12	0.11	0.1	0.093	0.087	0.065
NOV58	0.4	0	0.47	0.28	0.12	0.12	0.11	0.099	0.094	0.089	0.085	0.058
DEC58	0.43	0	0.51	0.29	0.12	0.11	0.11	0.096	0.089	0.083	0.077	0.052
1958	4.2	0.85	5	3.3	1.6	1.5	1.4	1.3	1.2	1.2	1.1	0.9
JAN59	0.63	0.38	0.67	0.55	0.44	0.43	0.43	0.42	0.42	0.42	0.41	0.4
FEB59	0.28	0	0.36	0.23	0.1	0.093	0.087	0.078	0.073	0.067	0.062	0.038
MAR59	0.24	0	0.32	0.21	0.11	0.098	0.092	0.085	0.08	0.075	0.07	0.052
APR59	0.19	0	0.25	0.15	0.086	0.079	0.074	0.07	0.066	0.063	0.062	0.046
MAY59	0.11	0.041	0.16	0.11	0.066	0.059	0.055	0.052	0.049	0.047	0.043	0.035
JUN59	0.078	0.058	0.11	0.083	0.049	0.044	0.039	0.038	0.036	0.033	0.03	0.025
JUL59	0.093	0.063	0.13	0.12	0.06	0.053	0.049	0.046	0.043	0.041	0.038	0.031
AUG59	0.24	0.17	0.28	0.21	0.069	0.062	0.059	0.054	0.051	0.048	0.045	0.036
SEP59	0.28	0.18	0.34	0.26	0.14	0.13	0.13	0.12	0.11	0.11	0.11	0.094
OCT59	0.16	0	0.21	0.15	0.075	0.069	0.066	0.062	0.059	0.056	0.053	0.044
NOV59	0.21	0	0.28	0.2	0.11	0.11	0.1	0.095	0.09	0.085	0.081	0.063
DEC59	0.29	0	0.36	0.26	0.14	0.13	0.13	0.12	0.11	0.11	0.1	0.08
1959	2.8	0.89	3.5	2.5	1.4	1.4	1.3	1.2	1.2	1.1	1.1	0.94
JAN60	0.99	0.5	1.1	0.93	0.73	0.71	0.7	0.69	0.68	0.67	0.66	0.6
FEB60	0.32	0	0.39	0.25	0.13	0.12	0.12	0.11	0.11	0.11	0.11	0.076
MAR60	0.43	0	0.5	0.27	0.13	0.12	0.11	0.1	0.095	0.09	0.085	0.054

Table A.4. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
APR60	0.2	0	0.28	0.19	0.11	0.1	0.093	0.087	0.083	0.079	0.074	0.054
MAY60	0.19	0.075	0.26	0.17	0.095	0.087	0.082	0.078	0.074	0.071	0.067	0.053
JUN60	0.13	0.081	0.18	0.14	0.078	0.069	0.064	0.062	0.058	0.055	0.051	0.042
JUL60	0.13	0.079	0.19	0.17	0.088	0.079	0.074	0.071	0.067	0.063	0.059	0.05
AUG60	0.29	0.19	0.34	0.25	0.083	0.075	0.071	0.065	0.061	0.057	0.053	0.043
SEP60	0.48	0.3	0.51	0.34	0.14	0.13	0.13	0.12	0.12	0.11	0.11	0.09
OCT60	0.32	0	0.38	0.26	0.12	0.11	0.11	0.098	0.094	0.09	0.086	0.072
NOV60	0.45	0	0.51	0.33	0.13	0.12	0.12	0.11	0.1	0.096	0.091	0.06
DEC60	0.49	0	0.59	0.38	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.074
1960	4.4	1.2	5.3	3.7	2	1.9	1.8	1.7	1.7	1.6	1.5	1.3
JAN61	1.1	0.45	1.2	0.91	0.64	0.63	0.62	0.6	0.59	0.58	0.57	0.52
FEB61	0.3	0	0.39	0.25	0.15	0.14	0.14	0.13	0.12	0.12	0.11	0.071
MAR61	0.35	0	0.45	0.3	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.079
APR61	0.29	0	0.4	0.27	0.19	0.18	0.17	0.16	0.16	0.15	0.15	0.12
MAY61	0.16	0.063	0.21	0.15	0.096	0.091	0.087	0.085	0.083	0.081	0.08	0.073
JUN61	0.08	0.058	0.12	0.098	0.064	0.058	0.053	0.052	0.049	0.047	0.044	0.038
JUL61	0.13	0.11	0.16	0.13	0.049	0.044	0.042	0.039	0.037	0.036	0.034	0.03
AUG61	0.23	0.13	0.28	0.22	0.1	0.096	0.093	0.087	0.083	0.08	0.076	0.062
SEP61	0.29	0.12	0.34	0.24	0.14	0.14	0.13	0.13	0.12	0.12	0.12	0.11
OCT61	0.23	0	0.28	0.19	0.097	0.094	0.092	0.085	0.083	0.08	0.079	0.073
NOV61	0.23	0	0.28	0.19	0.11	0.1	0.098	0.089	0.086	0.082	0.078	0.056
DEC61	0.24	0	0.27	0.16	0.084	0.082	0.079	0.073	0.071	0.069	0.069	0.045
1961	3.6	0.94	4.4	3.1	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.3
JAN62	0.86	0.57	0.92	0.79	0.68	0.68	0.67	0.66	0.66	0.65	0.65	0.62
FEB62	0.23	0	0.28	0.18	0.11	0.1	0.099	0.092	0.09	0.088	0.086	0.07
MAR62	0.37	0	0.43	0.25	0.13	0.13	0.12	0.11	0.1	0.099	0.095	0.064
APR62	0.34	0	0.45	0.23	0.15	0.15	0.14	0.13	0.12	0.12	0.12	0.092
MAY62	0.19	0.066	0.27	0.17	0.11	0.097	0.092	0.088	0.084	0.081	0.077	0.063
JUN62	0.14	0.1	0.2	0.15	0.084	0.075	0.07	0.068	0.065	0.062	0.058	0.05
JUL62	0.16	0.1	0.23	0.19	0.11	0.11	0.1	0.097	0.094	0.091	0.087	0.078
AUG62	0.28	0.16	0.36	0.28	0.15	0.14	0.13	0.13	0.12	0.12	0.11	0.1
SEP62	0.52	0.26	0.59	0.43	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.18
OCT62	0.24	0	0.31	0.2	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.11
NOV62	0.2	0	0.26	0.17	0.1	0.098	0.095	0.087	0.084	0.081	0.078	0.056
DEC62	0.21	0	0.28	0.19	0.12	0.11	0.11	0.1	0.098	0.094	0.09	0.064
1962	3.7	1.3	4.6	3.2	2.1	2.1	2	1.9	1.9	1.8	1.8	1.5
JAN63	0.66	0.52	0.7	0.65	0.59	0.58	0.58	0.58	0.57	0.57	0.57	0.56
FEB63	0.16	0	0.2	0.12	0.068	0.065	0.06	0.055	0.053	0.05	0.049	0.035
MAR63	0.23	0	0.27	0.16	0.066	0.061	0.057	0.051	0.048	0.045	0.042	0.03
APR63	0.2	0	0.25	0.16	0.081	0.075	0.07	0.065	0.062	0.058	0.054	0.036
MAY63	0.13	0.045	0.17	0.09	0.05	0.046	0.043	0.041	0.039	0.037	0.035	0.027
JUN63	0.087	0.067	0.12	0.083	0.041	0.035	0.032	0.03	0.028	0.026	0.023	0.018
JUL63	0.11	0.084	0.15	0.12	0.044	0.038	0.034	0.032	0.029	0.027	0.024	0.018
AUG63	0.19	0.13	0.22	0.16	0.049	0.043	0.041	0.037	0.034	0.031	0.029	0.022
SEP63	0.31	0.53	0.31	0.2	0.075	0.071	0.068	0.064	0.061	0.058	0.056	0.05

Table A.4. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
OCT63	0.23	0.44	0.27	0.18	0.06	0.054	0.051	0.045	0.041	0.038	0.035	0.031
NOV63	0.22	0.4	0.24	0.14	0.06	0.056	0.053	0.047	0.044	0.042	0.04	0.041
DEC63	0.24	0.45	0.26	0.15	0.058	0.054	0.051	0.045	0.042	0.039	0.037	0.026
1963	2.8	4.7	3.2	2.2	1.2	1.2	1.1	1.1	1.1	1	0.99	0.89
JAN64	0.6	0.82	0.61	0.49	0.38	0.37	0.37	0.36	0.36	0.36	0.35	0.34
FEB64	0.2	0.39	0.25	0.16	0.07	0.065	0.061	0.056	0.052	0.048	0.045	0.031
MAR64	0.26	0.49	0.3	0.18	0.077	0.072	0.068	0.062	0.058	0.055	0.051	0.034
APR64	0.3	0.57	0.36	0.16	0.083	0.076	0.071	0.066	0.062	0.059	0.055	0.042
MAY64	0.22	0.43	0.29	0.15	0.083	0.075	0.07	0.066	0.062	0.058	0.054	0.042
JUN64	0.087	0.17	0.12	0.082	0.048	0.043	0.038	0.036	0.034	0.031	0.028	0.022
JUL64	0.088	0.17	0.12	0.095	0.039	0.033	0.029	0.027	0.025	0.023	0.02	0.015
AUG64	0.18	0.32	0.21	0.15	0.052	0.046	0.044	0.04	0.037	0.035	0.032	0.025
SEP64	0.31	0.54	0.31	0.2	0.09	0.086	0.083	0.079	0.076	0.073	0.07	0.067
OCT64	0.13	0.26	0.17	0.12	0.048	0.044	0.042	0.039	0.036	0.035	0.033	0.029
NOV64	0.22	0.42	0.25	0.16	0.062	0.056	0.053	0.048	0.044	0.04	0.036	0.025
DEC64	0.22	0.42	0.24	0.13	0.055	0.051	0.047	0.042	0.04	0.037	0.035	0.019
1964	2.8	5	3.2	2.1	1.1	1	0.98	0.93	0.89	0.85	0.81	0.69
JAN65	0.41	0.59	0.44	0.34	0.28	0.27	0.27	0.26	0.26	0.26	0.25	0.24
FEB65	0.13	0.26	0.16	0.081	0.046	0.043	0.039	0.036	0.034	0.033	0.03	0.022
MAR65	0.16	0.32	0.2	0.11	0.06	0.056	0.052	0.049	0.046	0.044	0.041	0.032
APR65	0.14	0.28	0.18	0.095	0.057	0.053	0.049	0.046	0.044	0.042	0.04	0.034
MAY65	0.085	0.17	0.12	0.074	0.045	0.04	0.036	0.035	0.033	0.031	0.029	0.023
JUN65	0.073	0.14	0.1	0.068	0.038	0.033	0.03	0.029	0.026	0.025	0.023	0.018
JUL65	0.077	0.15	0.1	0.077	0.033	0.029	0.026	0.025	0.023	0.021	0.019	0.015
AUG65	0.12	0.22	0.15	0.1	0.036	0.031	0.029	0.027	0.025	0.023	0.021	0.016
SEP65	0.22	0.37	0.22	0.14	0.064	0.061	0.059	0.056	0.054	0.052	0.05	0.045
OCT65	0.18	0.33	0.19	0.11	0.036	0.033	0.031	0.027	0.025	0.023	0.021	0.017
NOV65	0.15	0.28	0.17	0.11	0.037	0.034	0.032	0.029	0.026	0.024	0.022	0.016
DEC65	0.14	0.27	0.16	0.1	0.041	0.038	0.036	0.033	0.031	0.029	0.027	0.02
1965	1.9	3.4	2.2	1.4	0.77	0.72	0.69	0.65	0.63	0.6	0.58	0.5
JAN66	0.29	0.39	0.3	0.24	0.2	0.2	0.2	0.19	0.19	0.19	0.19	0.18
FEB66	0.094	0.18	0.11	0.071	0.03	0.028	0.027	0.025	0.023	0.022	0.021	0.016
MAR66	0.12	0.23	0.14	0.086	0.038	0.035	0.033	0.03	0.029	0.027	0.025	0.016
APR66	0.12	0.23	0.14	0.071	0.037	0.034	0.032	0.03	0.029	0.027	0.025	0.019
MAY66	0.083	0.16	0.11	0.074	0.037	0.033	0.031	0.029	0.027	0.026	0.024	0.02
JUN66	0.054	0.1	0.073	0.058	0.024	0.02	0.018	0.017	0.016	0.015	0.013	0.011
JUL66	0.019	0.036	0.025	0.021	0.0076	0.0064	0.0059	0.0055	0.0052	0.0048	0.0045	0.0039
AUG66	0.045	0.08	0.046	0.032	0.007	0.0062	0.0059	0.0054	0.005	0.0046	0.0043	0.0034
SEP66	0.23	0.39	0.22	0.15	0.066	0.063	0.061	0.058	0.056	0.054	0.052	0.046
OCT66	0.12	0.23	0.14	0.096	0.053	0.051	0.05	0.046	0.044	0.042	0.04	0.037
NOV66	0.1	0.19	0.12	0.079	0.042	0.041	0.041	0.038	0.038	0.037	0.036	0.027
DEC66	0.12	0.23	0.14	0.089	0.045	0.042	0.04	0.037	0.036	0.034	0.033	0.021
1966	1.4	2.4	1.6	1.1	0.59	0.56	0.54	0.52	0.5	0.48	0.47	0.4
JAN67	0.31	0.42	0.33	0.27	0.23	0.23	0.22	0.22	0.22	0.22	0.21	0.2

Table A.4. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
FEB67	0.11	0.21	0.13	0.081	0.047	0.045	0.043	0.04	0.039	0.038	0.036	0.026
MAR67	0.11	0.22	0.15	0.1	0.057	0.055	0.052	0.049	0.047	0.046	0.044	0.034
APR67	0.14	0.27	0.17	0.11	0.062	0.059	0.057	0.054	0.052	0.051	0.048	0.039
MAY67	0.13	0.26	0.16	0.085	0.046	0.043	0.04	0.039	0.037	0.036	0.034	0.03
JUN67	0.048	0.094	0.069	0.051	0.033	0.029	0.026	0.025	0.024	0.022	0.02	0.016
JUL67	0.061	0.12	0.084	0.071	0.035	0.03	0.028	0.027	0.025	0.023	0.021	0.017
AUG67	0.12	0.22	0.14	0.11	0.039	0.035	0.033	0.031	0.029	0.027	0.026	0.021
SEP67	0.2	0.35	0.21	0.16	0.075	0.072	0.07	0.066	0.064	0.062	0.059	0.055
OCT67	0.11	0.21	0.13	0.087	0.04	0.038	0.036	0.034	0.032	0.031	0.029	0.023
NOV67	0.099	0.19	0.12	0.077	0.036	0.034	0.032	0.03	0.028	0.027	0.025	0.019
DEC67	0.097	0.19	0.12	0.079	0.038	0.036	0.035	0.032	0.03	0.028	0.026	0.019
1967	1.5	2.7	1.8	1.3	0.74	0.7	0.68	0.65	0.63	0.61	0.58	0.5
JAN68	0.25	0.33	0.26	0.22	0.18	0.18	0.17	0.17	0.17	0.17	0.17	0.16
FEB68	0.12	0.23	0.13	0.07	0.033	0.031	0.029	0.027	0.025	0.024	0.022	0.015
MAR68	0.098	0.19	0.12	0.079	0.039	0.036	0.034	0.031	0.03	0.028	0.026	0.019
APR68	0.097	0.19	0.12	0.078	0.039	0.027	0.025	0.024	0.023	0.023	0.022	0.02
MAY68	0.097	0.18	0.12	0.07	0.037	0.027	0.024	0.023	0.022	0.022	0.021	0.018
JUN68	0.041	0.078	0.056	0.04	0.02	0.013	0.011	0.011	0.01	0.01	0.0097	0.0086
JUL68	0.039	0.075	0.053	0.044	0.018	0.011	0.0093	0.0088	0.0085	0.0082	0.0079	0.0069
AUG68	0.099	0.18	0.12	0.084	0.03	0.019	0.016	0.015	0.014	0.014	0.013	0.011
SEP68	0.14	0.23	0.15	0.11	0.054	0.046	0.044	0.043	0.043	0.043	0.042	0.041
OCT68	0.086	0.16	0.1	0.065	0.025	0.016	0.014	0.013	0.013	0.013	0.012	0.01
NOV68	0.077	0.15	0.091	0.056	0.026	0.018	0.016	0.015	0.014	0.014	0.013	0.0089
DEC68	0.071	0.14	0.088	0.057	0.025	0.017	0.015	0.014	0.014	0.014	0.013	0.0083
1968	1.2	2.1	1.4	0.97	0.53	0.44	0.41	0.4	0.39	0.38	0.37	0.33
JAN69	0.17	0.22	0.18	0.15	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12
FEB69	0.049	0.095	0.066	0.046	0.023	0.017	0.015	0.014	0.014	0.013	0.013	0.0099
MAR69	0.077	0.15	0.097	0.058	0.031	0.022	0.018	0.017	0.017	0.016	0.016	0.013
APR69	0.046	0.092	0.065	0.041	0.025	0.018	0.015	0.014	0.014	0.014	0.013	0.011
MAY69	0.034	0.066	0.046	0.029	0.016	0.011	0.0092	0.0088	0.0085	0.0082	0.0078	0.0067
JUN69	0.044	0.084	0.058	0.042	0.018	0.01	0.0082	0.0077	0.0074	0.0071	0.0067	0.0056
JUL69	0.044	0.083	0.056	0.043	0.016	0.0098	0.0081	0.0077	0.0074	0.0072	0.0069	0.006
AUG69	0.085	0.16	0.095	0.069	0.024	0.016	0.014	0.013	0.013	0.012	0.012	0.01
SEP69	0.11	0.18	0.11	0.081	0.045	0.041	0.041	0.04	0.04	0.04	0.04	0.039
OCT69	0.041	0.077	0.047	0.033	0.015	0.012	0.011	0.01	0.01	0.0098	0.0096	0.0083
NOV69	0.033	0.062	0.039	0.027	0.013	0.011	0.011	0.0099	0.0098	0.0096	0.0094	0.0087
DEC69	0.042	0.079	0.051	0.037	0.017	0.013	0.011	0.011	0.011	0.011	0.01	0.007
1969	0.77	1.3	0.91	0.66	0.37	0.3	0.28	0.27	0.27	0.27	0.26	0.24
JAN70	0.13	0.19	0.14	0.11	0.087	0.081	0.079	0.078	0.078	0.078	0.077	0.076
FEB70	0.002	0.0053	0.0048	0.0031	0.0029	0.0032	0.003	0.0029	0.0029	0.003	0.0029	0.0022
MAR70	0.011	0.022	0.014	0.0091	0.0044	0.0029	0.0022	0.002	0.002	0.0018	0.0017	0.0013
APR70	0.042	0.082	0.053	0.033	0.016	0.011	0.0093	0.0087	0.0084	0.0081	0.0077	0.0062
MAY70	0.039	0.074	0.047	0.024	0.014	0.011	0.0098	0.0095	0.0094	0.0093	0.0093	0.0084
JUN70	0.028	0.054	0.037	0.02	[illegible]	0.0074	0.0062	0.0059	0.0058	0.0056	0.0053	0.0048
JUL70	0.046	0.087	0.059	0.039	0.016	0.011	0.0091	0.0086	0.0084	0.0081	0.0078	0.0068

Table A.4. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
AUG70	0.035	0.066	0.043	0.031	0.013	0.01	0.0094	0.009	0.0089	0.0088	0.0087	0.0082
SEP70	0.11	0.18	0.11	0.083	0.049	0.042	0.04	0.039	0.039	0.038	0.038	0.036
OCT70	0.057	0.11	0.07	0.048	0.024	0.019	0.017	0.016	0.016	0.016	0.016	0.014
NOV70	0.054	0.1	0.067	0.043	0.022	0.017	0.016	0.015	0.015	0.015	0.014	0.012
DEC70	0.054	0.1	0.067	0.042	0.021	0.016	0.015	0.014	0.014	0.013	0.013	0.0089
1970	0.61	1.1	0.72	0.49	0.28	0.23	0.22	0.21	0.21	0.2	0.2	0.18
JAN71	0.054	0.097	0.06	0.032	0.018	0.013	0.011	0.01	0.01	0.0097	0.0092	0.0069

Table A.5. Typical Representative Individual - Red Bone Marrow Equivalent Dose (millirem per year)

	Location											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1950	0.78	0.29	1.1	0.87	0.83	0.8	0.77	0.75	0.74	0.72	0.7	0.61
1951	0.62	0.25	0.86	0.7	0.66	0.62	0.6	0.59	0.58	0.56	0.54	0.46
1952	0.77	0.25	1.1	0.87	0.8	0.75	0.73	0.7	0.69	0.66	0.63	0.55
1953	0.93	0.27	1.3	1	0.88	0.82	0.79	0.75	0.74	0.71	0.68	0.51
1954	1.2	0.46	1.7	1.3	1.1	1.1	1.1	1	1	1	1	0.86
1955	1.5	0.58	2	1.6	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1
1956	1.7	0.73	2.2	1.7	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.1
1957	2.3	0.81	2.9	2.1	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.2
1958	2.5	0.88	3.1	2.2	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.2
1959	2.2	0.93	2.7	2.1	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.2
1960	3.3	1.3	4.1	3.1	2.3	2.3	2.2	2.1	2.1	2.1	2	1.7
1961	3	1	3.9	2.9	2.4	2.3	2.3	2.2	2.2	2.1	2.1	1.7
1962	3.2	1.3	4.1	3.1	2.5	2.5	2.4	2.3	2.3	2.3	2.2	2
1963	2.2	3.6	2.5	1.9	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.2
1964	2.1	3.5	2.4	1.7	1.2	1.2	1.2	1.1	1.1	1.1	1.1	0.91
1965	1.5	2.5	1.7	1.2	0.89	0.87	0.84	0.81	0.8	0.78	0.76	0.68
1966	1.2	2.1	1.4	1	0.76	0.74	0.73	0.7	0.69	0.67	0.65	0.56
1967	1.3	2.3	1.6	1.2	0.91	0.9	0.88	0.85	0.84	0.82	0.8	0.69
1968	1	1.7	1.2	0.88	0.65	0.61	0.58	0.57	0.56	0.55	0.54	0.47
1969	0.66	1.1	0.8	0.61	0.45	0.41	0.39	0.38	0.38	0.37	0.36	0.33
1970	0.48	0.81	0.57	0.42	0.32	0.3	0.28	0.27	0.27	0.27	0.26	0.24
1971	0.04	0.072	0.047	0.028	0.022	0.017	0.015	0.014	0.014	0.013	0.013	0.0091

Table A.6. Typical Representative Individual - Lower Large Intestine Equivalent Dose (millirem per year)

	Location											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1950	12	0.31	18	13	11	9.1	8.1	7.8	7.4	6.4	5.2	2.6
1951	9.9	0.27	15	11	9.6	8.1	7.3	6.9	6.6	5.8	4.7	2.2
1952	13	0.27	19	14	12	9.7	8.6	8.2	7.8	6.5	5.1	2.4
1953	16	0.28	23	16	12	9.6	8.5	8.1	7.7	6.6	5.3	2.3
1954	17	0.49	23	15	6.1	5.3	4.9	4.7	4.5	4.1	3.5	2.1
1955	20	0.61	27	18	6.9	6	5.5	5.3	5.1	4.6	3.9	2.2
1956	21	0.77	27	18	7.1	6.2	5.7	5.5	5.3	4.8	4.1	2.5
1957	29	0.83	37	23	7.9	6.9	6.2	5.5	5	4.4	3.8	2.4
1958	28	0.89	35	22	7.4	6.5	5.8	5.1	4.5	3.9	3.4	2.1
1959	14	0.95	19	13	5.8	5.1	4.7	4.3	3.9	3.5	3.1	2.2
1960	23	1.3	29	19	7.2	6.4	5.8	5.2	4.7	4.3	3.8	2.6
1961	17	1	22	15	5.8	5.2	4.8	4.3	3.9	3.6	3.3	2.3
1962	16	1.4	20	13	6	5.5	5.1	4.6	4.3	4	3.7	2.8
1963	13	25	17	11	4.3	3.8	3.5	3.2	2.9	2.6	2.3	1.7
1964	15	29	19	12	4.4	3.9	3.5	3.2	2.8	2.5	2.3	1.5
1965	9.8	19	12	7.6	3.2	2.9	2.6	2.4	2.1	1.9	1.7	1.2
1966	6	11	7.3	4.8	1.9	1.7	1.5	1.4	1.3	1.2	1	0.76
1967	6.8	13	8.7	6	2.5	2.2	2.1	1.9	1.7	1.6	1.4	1
1968	5.9	11	7.4	5	2.1	1.3	1.1	0.98	0.92	0.86	0.79	0.61
1969	3.3	6.3	4.3	3	1.3	0.78	0.61	0.58	0.55	0.53	0.51	0.43
1970	2.9	5.5	3.7	2.4	0.96	0.52	0.4	0.38	0.36	0.35	0.34	0.29
1971	0.31	0.59	0.36	0.18	0.067	0.029	0.021	0.019	0.018	0.017	0.015	0.011

Table A.7. Occupational Representative Individual - Effective Dose Equivalent (millirem per month and millirem per year)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
JAN50	0.94	1.8	1.3	0.93	0.74	0.59	0.52	0.49	0.47	0.38	0.3	0.16
FEB50	0.88	1.7	1.2	0.79	0.65	0.54	0.48	0.45	0.43	0.37	0.32	0.18
MAR50	0.86	1.7	1.2	0.67	0.55	0.45	0.4	0.38	0.36	0.32	0.27	0.13
APR50	0.62	1.3	0.87	0.48	0.4	0.33	0.29	0.28	0.27	0.25	0.21	0.14
MAY50	0.36	0.72	0.52	0.34	0.29	0.25	0.22	0.21	0.2	0.19	0.17	0.11
JUN50	0.16	0.31	0.23	0.17	0.15	0.13	0.12	0.12	0.11	0.11	0.095	0.072
JUL50	0.18	0.36	0.27	0.25	0.2	0.17	0.16	0.15	0.15	0.14	0.12	0.087
AUG50	0.4	0.8	0.59	0.51	0.41	0.33	0.3	0.29	0.27	0.25	0.21	0.12
SEP50	0.64	1.3	0.9	0.74	0.59	0.47	0.42	0.4	0.38	0.33	0.27	0.16
OCT50	0.98	1.9	1.3	0.95	0.76	0.61	0.54	0.52	0.49	0.42	0.35	0.21
NOV50	0.99	2	1.3	0.94	0.76	0.6	0.54	0.51	0.49	0.42	0.35	0.22
DEC50	0.98	2	1.3	0.9	0.74	0.61	0.54	0.51	0.49	0.42	0.35	0.24
1950	8	16	11	7.7	6.2	5.1	4.5	4.3	4.1	3.6	3	1.8
JAN51	0.63	1.2	0.83	0.61	0.47	0.36	0.32	0.29	0.28	0.24	0.19	0.077
FEB51	0.72	1.4	0.92	0.59	0.45	0.35	0.3	0.28	0.26	0.23	0.19	0.093
MAR51	0.85	1.7	1.1	0.71	0.54	0.42	0.36	0.34	0.32	0.28	0.23	0.12
APR51	0.55	1.1	0.75	0.41	0.33	0.27	0.23	0.22	0.21	0.19	0.16	0.11
MAY51	0.2	0.4	0.29	0.2	0.17	0.15	0.13	0.13	0.12	0.11	0.1	0.074
JUN51	0.19	0.38	0.27	0.22	0.19	0.16	0.14	0.14	0.13	0.12	0.11	0.081
JUL51	0.24	0.47	0.35	0.32	0.26	0.22	0.2	0.2	0.18	0.17	0.15	0.11
AUG51	0.54	1.1	0.76	0.66	0.51	0.4	0.35	0.34	0.32	0.28	0.23	0.14
SEP51	0.88	1.7	1.2	1	0.8	0.63	0.56	0.54	0.51	0.43	0.35	0.21
OCT51	0.83	1.6	1.1	0.84	0.66	0.52	0.46	0.44	0.42	0.36	0.29	0.16
NOV51	0.93	1.8	1.3	0.91	0.73	0.58	0.51	0.48	0.46	0.39	0.32	0.16
DEC51	0.89	1.7	1.2	0.81	0.64	0.5	0.44	0.42	0.4	0.34	0.27	0.11
1951	7.5	15	10	7.3	5.7	4.6	4	3.8	3.6	3.1	2.6	1.4
JAN52	0.91	1.8	1.3	0.94	0.75	0.58	0.52	0.49	0.47	0.39	0.32	0.14
FEB52	0.82	1.6	1.1	0.68	0.52	0.4	0.35	0.33	0.31	0.26	0.21	0.092
MAR52	0.89	1.7	1.2	0.77	0.6	0.46	0.4	0.38	0.36	0.31	0.25	0.13
APR52	0.8	1.6	1.1	0.42	0.33	0.26	0.22	0.21	0.2	0.18	0.15	0.093
MAY52	0.31	0.61	0.45	0.25	0.2	0.17	0.15	0.15	0.14	0.13	0.11	0.079
JUN52	0.22	0.43	0.32	0.23	0.18	0.15	0.13	0.13	0.12	0.11	0.098	0.069
JUL52	0.37	0.73	0.53	0.44	0.34	0.27	0.24	0.23	0.22	0.2	0.16	0.11
AUG52	0.57	1.1	0.79	0.66	0.5	0.37	0.32	0.31	0.29	0.25	0.2	0.12
SEP52	1.1	2	1.4	1	0.74	0.54	0.46	0.43	0.41	0.32	0.25	0.14
OCT52	1.5	2.8	1.9	1.4	1	0.77	0.65	0.62	0.59	0.46	0.36	0.2
NOV52	1.3	2.5	1.7	1.3	0.97	0.73	0.62	0.59	0.56	0.45	0.35	0.27
DEC52	1.7	3.3	2.3	1.7	1.2	0.94	0.81	0.76	0.72	0.57	0.44	0.26
1952	10	20	14	9.8	7.4	5.7	4.9	4.6	4.4	3.6	2.9	1.7
JAN53	1.8	3.4	2.1	1.2	0.94	0.7	0.59	0.53	0.5	0.4	0.3	0.081
FEB53	1.3	2.4	1.6	1	0:78	0.59	0.51	0.47	0.44	0.37	0.3	0.12
MAR53	1.3	2.5	1.7	1.1	0.84	0.63	0.53	0.5	0.47	0.4	0.32	0.16
APR53	0.96	1.9	1.3	0.76	0.56	0.42	0.35	0.33	0.31	0.26	0.21	0.11
MAY53	0.92	1.8	1.2	0.68	0.52	0.4	0.33	0.32	0.3	0.27	0.22	0.12

Table A.7. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
JUN53	0.26	0.52	0.37	0.26	0.21	0.17	0.15	0.15	0.14	0.12	0.11	0.074
JUL53	0.36	0.71	0.52	0.43	0.33	0.26	0.23	0.23	0.21	0.19	0.16	0.11
AUG53	0.91	1.8	1.3	1.1	0.79	0.59	0.51	0.49	0.46	0.39	0.3	0.17
SEP53	1.2	2.3	1.6	1.3	1	0.74	0.64	0.61	0.58	0.47	0.37	0.2
OCT53	1.6	3.1	2.1	1.7	1.2	0.91	0.78	0.74	0.7	0.56	0.43	0.22
NOV53	1.9	3.4	1.9	1.2	0.32	0.28	0.27	0.25	0.25	0.22	0.2	0.13
DEC53	2.1	3.6	1.9	1.1	0.3	0.27	0.25	0.23	0.23	0.21	0.19	0.084
1953	14	27	18	12	7.8	6	5.1	4.9	4.6	3.9	3.1	1.6
JAN54	1.7	3.1	1.8	1.1	0.35	0.32	0.3	0.28	0.27	0.25	0.22	0.097
FEB54	1.7	3.1	1.7	0.94	0.38	0.35	0.33	0.3	0.3	0.28	0.26	0.14
MAR54	1.7	3	1.8	1	0.39	0.36	0.33	0.31	0.31	0.28	0.26	0.18
APR54	1.8	3.2	1.8	0.8	0.36	0.33	0.3	0.29	0.28	0.26	0.24	0.17
MAY54	0.71	1.4	0.92	0.53	0.29	0.26	0.24	0.24	0.23	0.22	0.19	0.15
JUN54	0.38	0.75	0.54	0.43	0.26	0.23	0.21	0.21	0.2	0.18	0.17	0.13
JUL54	0.41	0.8	0.58	0.51	0.28	0.24	0.22	0.21	0.2	0.19	0.17	0.13
AUG54	0.8	1.5	1	0.85	0.35	0.3	0.28	0.27	0.27	0.25	0.22	0.17
SEP54	1.2	2.2	1.4	1.1	0.38	0.34	0.33	0.31	0.31	0.29	0.26	0.2
OCT54	1.7	3.1	1.8	1.2	0.42	0.39	0.37	0.35	0.35	0.32	0.3	0.23
NOV54	1.5	2.8	1.6	1.1	0.39	0.37	0.35	0.34	0.33	0.31	0.29	0.22
DEC54	1.7	3.1	1.8	1.2	0.4	0.37	0.35	0.34	0.33	0.31	0.29	0.2
1954	15	28	17	11	4.2	3.9	3.6	3.4	3.4	3.1	2.9	2
JAN55	1.8	3.2	1.9	1.2	0.34	0.31	0.29	0.27	0.27	0.24	0.22	0.12
FEB55	1.2	2.2	1.3	0.88	0.32	0.3	0.29	0.27	0.27	0.26	0.24	0.17
MAR55	2	3.7	2.2	1.5	0.48	0.44	0.41	0.4	0.39	0.36	0.33	0.21
APR55	1.9	3.5	2.1	1.1	0.42	0.38	0.36	0.35	0.34	0.32	0.3	0.19
MAY55	1.8	3.3	2.1	0.93	0.46	0.41	0.38	0.37	0.36	0.34	0.31	0.22
JUN55	0.56	1.1	0.8	0.56	0.34	0.31	0.28	0.28	0.27	0.25	0.23	0.18
JUL55	0.52	1	0.73	0.63	0.31	0.26	0.24	0.23	0.22	0.21	0.18	0.14
AUG55	1.1	2	1.3	1.1	0.38	0.33	0.31	0.3	0.29	0.27	0.24	0.18
SEP55	1.6	2.9	1.7	1.2	0.38	0.35	0.33	0.32	0.32	0.3	0.27	0.22
OCT55	2.3	4.1	2.4	1.5	0.51	0.47	0.46	0.43	0.43	0.4	0.37	0.25
NOV55	2.3	4.1	2.3	1.5	0.54	0.51	0.49	0.46	0.45	0.43	0.4	0.25
DEC55	2.8	5.1	2.7	1.5	0.57	0.53	0.49	0.46	0.45	0.42	0.38	0.18
1955	20	36	22	13	5.1	4.6	4.3	4.1	4	3.8	3.5	2.3
JAN56	2.1	3.7	2.1	1.2	0.42	0.38	0.35	0.32	0.31	0.28	0.25	0.11
FEB56	1.9	3.6	2.1	1.3	0.51	0.47	0.45	0.42	0.41	0.39	0.36	0.24
MAR56	2.5	4.5	2.4	1.2	0.53	0.49	0.46	0.43	0.42	0.4	0.37	0.24
APR56	1.2	2.2	1.4	0.78	0.4	0.35	0.32	0.31	0.3	0.28	0.26	0.2
MAY56	0.59	1.2	0.82	0.53	0.32	0.28	0.25	0.25	0.23	0.22	0.2	0.15
JUN56	0.53	1	0.72	0.55	0.32	0.28	0.25	0.24	0.23	0.22	0.19	0.15
JUL56	0.91	1.8	1.2	1	0.43	0.36	0.33	0.33	0.31	0.29	0.26	0.2
AUG56	1.8	3.4	2.1	1.5	0.51	0.46	0.43	0.42	0.41	0.38	0.35	0.27
SEP56	2.4	4.3	2.5	1.6	0.54	0.5	0.48	0.46	0.45	0.42	0.39	0.32
OCT56	2	3.6	2	1.2	0.44	0.41	0.4	0.38	0.38	0.36	0.34	0.28
NOV56	2.4	4.2	2.4	1.4	0.45	0.42	0.4	0.38	0.37	0.35	0.32	0.22

Table A.7. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
DEC56	3.1	5.5	2.9	1.6	0.48	0.44	0.42	0.39	0.38	0.35	0.32	0.2
1956	21	39	23	14	5.4	4.9	4.5	4.3	4.2	3.9	3.6	2.6
JAN57	2.8	5.1	2.9	1.8	0.43	0.38	0.35	0.33	0.32	0.29	0.26	0.15
FEB57	2.9	5.2	3	1.7	0.49	0.44	0.41	0.38	0.37	0.34	0.31	0.2
MAR57	3.9	6.7	3.4	1.3	0.41	0.36	0.33	0.29	0.27	0.24	0.22	0.13
APR57	3.3	5.9	3.2	1.3	0.48	0.42	0.38	0.34	0.31	0.29	0.27	0.19
MAY57	1	1.9	1.3	0.75	0.41	0.36	0.31	0.3	0.27	0.25	0.22	0.17
JUN57	0.71	1.4	0.95	0.68	0.32	0.27	0.23	0.22	0.2	0.18	0.16	0.12
JUL57	1.7	3.1	2.1	1.5	0.46	0.4	0.37	0.34	0.31	0.29	0.27	0.21
AUG57	2.7	4.9	2.9	2	0.56	0.5	0.47	0.43	0.4	0.37	0.35	0.28
SEP57	3.8	6.5	3.5	2	0.61	0.57	0.54	0.49	0.46	0.43	0.41	0.34
OCT57	4	6.8	3.6	2	0.62	0.59	0.56	0.51	0.49	0.47	0.45	0.37
NOV57	4.3	7.2	3.8	2.1	0.66	0.62	0.6	0.55	0.52	0.5	0.49	0.38
DEC57	5	8.6	4.5	2.4	0.73	0.69	0.65	0.59	0.56	0.54	0.52	0.32
1957	36	63	35	19	6.2	5.6	5.2	4.8	4.5	4.2	3.9	2.9
JAN58	4.9	8.1	4.2	2.1	0.45	0.4	0.37	0.31	0.28	0.25	0.23	0.098
FEB58	4	7	3.7	1.7	0.56	0.51	0.46	0.4	0.38	0.36	0.33	0.19
MAR58	3.2	5.6	3.2	1.7	0.48	0.42	0.39	0.34	0.32	0.29	0.27	0.19
APR58	2.9	5.3	3.1	1.5	0.58	0.52	0.47	0.43	0.41	0.38	0.36	0.26
MAY58	1.6	2.9	1.9	1	0.47	0.41	0.36	0.34	0.31	0.29	0.26	0.21
JUN58	1	1.9	1.3	0.97	0.39	0.32	0.27	0.25	0.23	0.2	0.17	0.12
JUL58	1.9	3.4	2.2	1.6	0.45	0.38	0.35	0.32	0.29	0.26	0.24	0.18
AUG58	2.9	5.2	3	2	0.5	0.45	0.42	0.38	0.35	0.33	0.31	0.25
SEP58	3.7	6.1	3.2	1.8	0.37	0.34	0.32	0.29	0.27	0.26	0.24	0.21
OCT58	4.4	7.5	4	2.3	0.61	0.57	0.54	0.48	0.45	0.42	0.4	0.3
NOV58	4.1	7	3.6	1.8	0.56	0.52	0.49	0.45	0.43	0.4	0.39	0.27
DEC58	4.5	7.8	4	2	0.56	0.51	0.48	0.43	0.4	0.37	0.35	0.24
1958	39	68	38	21	6	5.3	4.9	4.4	4.1	3.8	3.5	2.5
JAN59	3.2	5.4	2.8	1.4	0.31	0.27	0.25	0.22	0.2	0.18	0.16	0.085
FEB59	3	5.3	2.9	1.7	0.48	0.43	0.4	0.36	0.33	0.3	0.28	0.17
MAR59	3.5	6.1	3.5	2	0.53	0.47	0.43	0.39	0.37	0.34	0.32	0.24
APR59	3.1	5.4	3.2	1.7	0.48	0.41	0.37	0.34	0.32	0.3	0.28	0.21
MAY59	1.5	2.8	1.9	1.3	0.47	0.38	0.33	0.31	0.28	0.25	0.22	0.16
JUN59	0.91	1.7	1.2	0.87	0.4	0.33	0.27	0.26	0.23	0.2	0.17	0.12
JUL59	1	2	1.4	1.2	0.41	0.33	0.29	0.27	0.24	0.22	0.19	0.14
AUG59	3	5.1	3.1	2.1	0.38	0.31	0.29	0.26	0.24	0.22	0.2	0.16
SEP59	2.7	4.8	2.9	1.9	0.53	0.48	0.46	0.42	0.4	0.38	0.37	0.31
OCT59	2.3	4	2.4	1.5	0.39	0.34	0.32	0.29	0.27	0.26	0.24	0.2
NOV59	3.4	5.9	3.4	2.1	0.57	0.51	0.48	0.45	0.42	0.39	0.37	0.29
DEC59	4.5	7.9	4.2	2.5	0.69	0.63	0.6	0.55	0.52	0.5	0.47	0.37
1959	32	57	33	20	5.6	4.9	4.5	4.1	3.8	3.5	3.3	2.5
JAN60	6.2	11	5.7	3.3	1.1	0.99	0.94	0.86	0.81	0.77	0.72	0.48
FEB60	5.2	8.7	4.5	2.3	0.6	0.57	0.55	0.51	0.5	0.49	0.48	0.35
MAR60	7	12	5.7	2.5	0.6	0.55	0.51	0.46	0.43	0.41	0.39	0.25

Table A.7. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
APR60	3.6	6.4	4	2.4	0.72	0.58	0.51	0.47	0.43	0.39	0.36	0.25
MAY60	2.8	5	3.3	1.9	0.64	0.53	0.47	0.43	0.4	0.37	0.33	0.25
JUN60	1.3	2.5	1.8	1.3	0.52	0.43	0.37	0.35	0.32	0.29	0.26	0.2
JUL60	1.4	2.6	1.8	1.5	0.53	0.43	0.39	0.36	0.33	0.31	0.28	0.23
AUG60	3.4	5.8	3.4	2.3	0.43	0.36	0.33	0.3	0.28	0.26	0.24	0.19
SEP60	5	8.5	4.4	2.4	0.52	0.48	0.46	0.42	0.4	0.37	0.35	0.29
OCT60	4.8	8	4	2.2	0.54	0.51	0.49	0.45	0.43	0.41	0.4	0.34
NOV60	8.2	13	6.5	3.2	0.61	0.56	0.54	0.48	0.46	0.44	0.42	0.28
DEC60	6.7	11	5.5	2.8	0.78	0.73	0.7	0.63	0.6	0.56	0.53	0.34
1960	56	94	51	28	7.5	6.7	6.3	5.7	5.4	5.1	4.8	3.4
JAN61	8.3	14	6.8	3.4	0.87	0.8	0.75	0.67	0.63	0.58	0.53	0.31
FEB61	3.9	7	3.9	2.1	0.72	0.66	0.63	0.57	0.55	0.52	0.5	0.33
MAR61	5.7	9.9	5.3	3	0.88	0.81	0.76	0.7	0.66	0.62	0.59	0.37
APR61	4.2	7.5	4.4	2.5	0.94	0.87	0.82	0.77	0.75	0.72	0.69	0.56
MAY61	2.3	4.3	2.7	1.7	0.63	0.55	0.5	0.47	0.44	0.42	0.4	0.34
JUN61	0.92	1.7	1.2	1	0.5	0.42	0.36	0.34	0.31	0.29	0.25	0.19
JUL61	1.7	3.1	2	1.5	0.33	0.27	0.24	0.22	0.2	0.18	0.16	0.14
AUG61	2.5	4.4	2.5	1.7	0.48	0.45	0.43	0.4	0.38	0.36	0.35	0.28
SEP61	2.2	3.8	2.1	1.3	0.51	0.49	0.48	0.44	0.43	0.42	0.41	0.37
OCT61	3.4	5.6	2.7	1.4	0.44	0.43	0.42	0.39	0.38	0.37	0.36	0.34
NOV61	3.9	6.3	3.1	1.6	0.49	0.47	0.45	0.41	0.4	0.38	0.36	0.26
DEC61	4.3	6.8	3	1.4	0.39	0.37	0.36	0.33	0.33	0.32	0.32	0.21
1961	43	74	40	23	7.2	6.6	6.2	5.7	5.5	5.2	4.9	3.7
JAN62	4.4	7.2	3.5	1.8	0.53	0.49	0.47	0.43	0.41	0.38	0.36	0.25
FEB62	3.9	6.6	3.3	1.7	0.5	0.48	0.46	0.42	0.42	0.4	0.39	0.33
MAR62	5.8	9.5	4.5	2	0.6	0.58	0.55	0.5	0.48	0.46	0.44	0.3
APR62	5.5	9.5	5.2	2.3	0.81	0.73	0.67	0.62	0.59	0.55	0.54	0.43
MAY62	2.5	4.6	3	1.7	0.64	0.54	0.48	0.45	0.42	0.39	0.36	0.29
JUN62	1.6	3.1	2.1	1.5	0.58	0.47	0.42	0.39	0.36	0.33	0.3	0.23
JUL62	1.8	3.3	2.2	1.7	0.61	0.54	0.5	0.47	0.45	0.43	0.41	0.35
AUG62	3	5.3	3.2	2.3	0.7	0.65	0.62	0.58	0.56	0.54	0.52	0.46
SEP62	4.8	8.1	4.3	2.6	1	1	0.99	0.91	0.88	0.85	0.82	0.68
OCT62	3.8	6.4	3.2	1.6	0.61	0.61	0.6	0.58	0.58	0.58	0.59	0.5
NOV62	2.9	4.9	2.6	1.3	0.47	0.45	0.43	0.4	0.39	0.37	0.36	0.26
DEC62	3	5.2	2.8	1.5	0.56	0.53	0.5	0.47	0.45	0.43	0.42	0.3
1962	43	74	40	22	7.7	7.1	6.7	6.2	6	5.7	5.5	4.4
JAN63	2.5	4.2	2.2	1.2	0.29	0.27	0.25	0.23	0.22	0.2	0.19	0.14
FEB63	2.6	4.4	2.3	1.1	0.33	0.3	0.28	0.25	0.24	0.23	0.22	0.16
MAR63	4.5	7.6	3.8	1.8	0.32	0.28	0.26	0.23	0.22	0.2	0.19	0.14
APR63	4	7	3.8	2	0.42	0.37	0.34	0.31	0.29	0.27	0.25	0.17
MAY63	1.7	3.1	1.9	0.93	0.3	0.25	0.22	0.21	0.19	0.18	0.16	0.12
JUN63	1	1.9	1.3	0.89	0.31	0.24	0.21	0.19	0.17	0.15	0.12	0.086
JUL63	1.4	2.5	1.6	1.2	0.29	0.22	0.19	0.17	0.15	0.13	0.11	0.082
AUG63	2.3	3.9	2.2	1.5	0.24	0.2	0.19	0.17	0.15	0.14	0.13	0.099
SEP63	3.3	5.4	2.7	1.4	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.11

Table A.7. (contd)

	Location											
Month/Year	1	2	3	4	5	6	7	8	9	10	11	12
OCT63	3.4	5.5	2.7	1.4	0.26	0.24	0.23	0.2	0.18	0.17	0.16	0.14
NOV63	3.8	6.1	2.7	1.3	0.27	0.25	0.24	0.21	0.2	0.19	0.18	0.19
DEC63	4.5	7.3	3.3	1.5	0.26	0.24	0.23	0.2	0.19	0.18	0.17	0.12
1963	35	59	31	16	3.5	3.1	2.8	2.5	2.3	2.2	2	1.6
JAN64	4.6	7.2	3.2	1.4	0.23	0.21	0.19	0.17	0.15	0.14	0.12	0.042
FEB64	3.1	5.3	2.7	1.4	0.32	0.29	0.27	0.25	0.23	0.22	0.2	0.14
MAR64	4.1	6.8	3.2	1.5	0.35	0.33	0.31	0.28	0.26	0.25	0.23	0.16
APR64	4.3	7	3.4	1.3	0.38	0.34	0.32	0.29	0.28	0.26	0.25	0.19
MAY64	2.9	5.2	3.1	1.5	0.49	0.41	0.36	0.34	0.31	0.28	0.25	0.19
JUN64	1.1	2	1.4	0.91	0.43	0.35	0.29	0.27	0.24	0.21	0.17	0.12
JUL64	1.2	2.1	1.4	1.1	0.34	0.25	0.21	0.19	0.16	0.14	0.12	0.074
AUG64	2.2	3.8	2.3	1.5	0.28	0.23	0.21	0.19	0.17	0.16	0.15	0.11
SEP64	3.2	5.3	2.7	1.4	0.29	0.26	0.25	0.23	0.22	0.2	0.19	0.18
OCT64	2.4	4.1	2.2	1.3	0.23	0.2	0.19	0.17	0.16	0.16	0.15	0.13
NOV64	4.1	6.7	3.3	1.7	0.28	0.25	0.24	0.22	0.2	0.18	0.16	0.11
DEC64	4.5	7.3	3.3	1.4	0.27	0.24	0.22	0.19	0.18	0.17	0.16	0.086
1964	38	63	32	16	3.9	3.4	3.1	2.8	2.6	2.4	2.2	1.5
JAN65	3.1	5.2	2.5	1.1	0.26	0.23	0.21	0.18	0.16	0.15	0.14	0.069
FEB65	2.3	4.1	2.1	0.92	0.26	0.22	0.19	0.17	0.16	0.15	0.14	0.1
MAR65	2.9	5	2.6	1.2	0.32	0.28	0.25	0.23	0.22	0.2	0.19	0.15
APR65	2.6	4.5	2.5	1.1	0.33	0.28	0.25	0.23	0.22	0.2	0.19	0.16
MAY65	1.2	2.2	1.5	0.86	0.34	0.27	0.23	0.22	0.2	0.18	0.15	0.11
JUN65	0.88	1.7	1.1	0.73	0.31	0.26	0.21	0.2	0.17	0.16	0.13	0.093
JUL65	0.91	1.7	1.1	0.79	0.23	0.18	0.15	0.14	0.12	0.11	0.096	0.07
AUG65	1.4	2.4	1.5	0.99	0.19	0.16	0.14	0.13	0.11	0.1	0.094	0.074
SEP65	2.1	3.6	1.8	0.95	0.17	0.15	0.14	0.13	0.12	0.11	0.1	0.08
OCT65	2.9	4.7	2.2	1	0.17	0.15	0.14	0.12	0.11	0.1	0.097	0.078
NOV65	2.4	4	2	0.99	0.17	0.15	0.14	0.13	0.12	0.11	0.099	0.075
DEC65	2.6	4.3	2.1	1.1	0.2	0.18	0.17	0.15	0.14	0.13	0.12	0.09
1965	25	43	23	12	3	2.5	2.2	2	1.9	1.7	1.5	1.1
JAN66	2.5	4	1.8	0.83	0.13	0.12	0.11	0.1	0.091	0.083	0.074	0.042
FEB66	2	3.4	1.7	0.89	0.15	0.13	0.12	0.11	0.11	0.1	0.096	0.073
MAR66	2.5	4.2	2.1	1	0.19	0.17	0.15	0.14	0.13	0.12	0.11	0.075
APR66	2.3	3.8	1.9	0.79	0.19	0.17	0.15	0.14	0.13	0.13	0.12	0.089
MAY66	1.3	2.3	1.4	0.88	0.25	0.2	0.17	0.16	0.14	0.13	0.12	0.09
JUN66	0.71	1.3	0.91	0.7	0.21	0.16	0.13	0.12	0.1	0.091	0.075	0.053
JUL66	0.27	0.5	0.33	0.27	0.065	0.048	0.041	0.037	0.032	0.028	0.024	0.019
AUG66	0.65	1.1	0.61	0.38	0.04	0.033	0.03	0.026	0.023	0.021	0.02	0.015
SEP66	2.5	4.2	2	1.1	0.18	0.16	0.16	0.14	0.13	0.12	0.11	0.089
OCT66	2.3	3.8	1.8	0.97	0.25	0.24	0.23	0.21	0.2	0.19	0.19	0.17
NOV66	2.2	3.6	1.7	0.85	0.2	0.19	0.19	0.18	0.17	0.17	0.16	0.13
DEC66	2.6	4.3	2	1	0.21	0.2	0.19	0.17	0.16	0.16	0.15	0.097
1966	22	36	18	9.7	2.1	1.8	1.7	1.5	1.4	1.3	1.3	0.94
JAN67	2.5	4.1	2	0.99	0.21	0.19	0.18	0.16	0.15	0.14	0.13	0.069

Table A.7. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
FEB67	2.3	3.8	1.8	0.92	0.23	0.21	0.2	0.19	0.18	0.18	0.17	0.12
MAR67	2.1	3.6	1.9	1.1	0.28	0.26	0.25	0.23	0.22	0.21	0.2	0.16
APR67	2.5	4.3	2.3	1.2	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.18
MAY67	1.9	3.4	1.8	0.85	0.27	0.23	0.21	0.2	0.18	0.17	0.16	0.14
JUN67	0.53	1	0.7	0.51	0.26	0.22	0.18	0.17	0.16	0.14	0.12	0.084
JUL67	0.7	1.3	0.89	0.71	0.24	0.19	0.17	0.15	0.14	0.12	0.11	0.082
AUG67	1.4	2.5	1.5	1	0.2	0.17	0.16	0.14	0.13	0.12	0.12	0.097
SEP67	1.9	3.2	1.6	0.99	0.22	0.2	0.19	0.18	0.17	0.16	0.15	0.13
OCT67	2	3.3	1.7	0.87	0.19	0.17	0.17	0.15	0.15	0.14	0.13	0.11
NOV67	1.8	3.1	1.6	0.8	0.17	0.16	0.15	0.14	0.13	0.12	0.12	0.089
DEC67	1.8	3.1	1.6	0.91	0.19	0.17	0.16	0.15	0.14	0.13	0.12	0.088
1967	21	37	19	11	2.8	2.5	2.3	2.1	2	1.9	1.7	1.3
JAN68	1.8	3	1.4	0.75	0.12	0.1	0.096	0.085	0.077	0.07	0.063	0.036
FEB68	2.2	3.7	1.7	0.77	0.17	0.15	0.14	0.12	0.12	0.11	0.099	0.067
MAR68	1.7	3	1.6	0.91	0.21	0.18	0.17	0.15	0.14	0.13	0.12	0.086
APR68	1.7	2.9	1.6	0.86	0.2	0.13	0.11	0.11	0.11	0.11	0.1	0.093
MAY68	1.4	2.4	1.4	0.72	0.2	0.12	0.11	0.1	0.1	0.099	0.096	0.084
JUN68	0.48	0.9	0.61	0.42	0.15	0.071	0.053	0.05	0.048	0.046	0.044	0.039
JUL68	0.46	0.84	0.56	0.44	0.12	0.056	0.043	0.04	0.039	0.037	0.035	0.031
AUG68	1.1	2	1.2	0.75	0.15	0.085	0.071	0.067	0.065	0.063	0.06	0.051
SEP68	1.2	2.1	1.1	0.67	0.13	0.086	0.078	0.075	0.074	0.072	0.071	0.064
OCT68	1.5	2.6	1.3	0.68	0.12	0.073	0.065	0.061	0.06	0.059	0.058	0.047
NOV68	1.5	2.5	1.2	0.62	0.12	0.081	0.073	0.068	0.066	0.064	0.061	0.041
DEC68	1.3	2.3	1.2	0.66	0.12	0.079	0.068	0.065	0.064	0.064	0.062	0.039
1968	16	28	15	8.3	1.8	1.2	1.1	1	0.96	0.92	0.87	0.68
JAN69	1.1	1.9	1	0.53	0.1	0.054	0.043	0.04	0.038	0.037	0.034	0.023
FEB69	0.92	1.6	0.97	0.58	0.13	0.077	0.067	0.064	0.063	0.061	0.059	0.046
MAR69	1.3	2.3	1.3	0.64	0.16	0.1	0.084	0.079	0.077	0.075	0.072	0.062
APR69	0.77	1.4	0.89	0.52	0.18	0.092	0.071	0.067	0.065	0.063	0.06	0.051
MAY69	0.51	0.95	0.63	0.38	0.14	0.064	0.046	0.043	0.041	0.039	0.037	0.031
JUN69	0.54	1	0.67	0.46	0.14	0.057	0.039	0.036	0.035	0.033	0.03	0.025
JUL69	0.54	0.97	0.62	0.45	0.1	0.048	0.037	0.035	0.034	0.033	0.031	0.027
AUG69	0.97	1.7	0.94	0.61	0.12	0.073	0.063	0.059	0.058	0.056	0.054	0.046
SEP69	1	1.7	0.85	0.47	0.082	0.065	0.064	0.061	0.061	0.06	0.06	0.056
OCT69	0.86	1.5	0.74	0.41	0.074	0.055	0.05	0.047	0.046	0.046	0.044	0.039
NOV69	0.69	1.2	0.61	0.36	0.065	0.049	0.049	0.046	0.046	0.045	0.044	0.04
DEC69	0.87	1.5	0.82	0.49	0.084	0.059	0.053	0.051	0.05	0.049	0.048	0.033
1969	10	18	10	5.9	1.4	0.79	0.67	0.63	0.61	0.6	0.57	0.48
JAN70	1.3	2.2	1.1	0.53	0.067	0.03	0.02	0.018	0.017	0.016	0.014	0.0065
FEB70	0.039	0.093	0.069	0.035	0.014	0.014	0.014	0.013	0.013	0.014	0.014	0.01
MAR70	0.19	0.34	0.17	0.09	0.021	0.013	0.01	0.0094	0.0091	0.0086	0.0081	0.0063
APR70	0.69	1.2	0.64	0.34	0.079	0.052	0.043	0.04	0.039	0.038	0.036	0.029
MAY70	0.53	0.92	0.51	0.23	0.078	0.051	0.045	0.044	0.043	0.043	0.043	0.039
JUN70	0.32	0.57	0.37	0.19	0.069	0.036	0.028	0.027	0.026	0.025	0.024	0.021
JUL70	0.49	0.87	0.55	0.33	0.083	0.049	0.041	0.039	0.038	0.037	0.035	0.031

Table A.7. (contd)

Month/Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
AUG70	0.38	0.66	0.38	0.25	0.062	0.046	0.043	0.041	0.041	0.04	0.04	0.038
SEP70	0.85	1.4	0.74	0.41	0.098	0.069	0.059	0.055	0.053	0.052	0.05	0.044
OCT70	0.87	1.5	0.77	0.42	0.11	0.086	0.08	0.076	0.075	0.074	0.073	0.064
NOV70	0.82	1.4	0.72	0.38	0.1	0.079	0.075	0.071	0.07	0.069	0.068	0.054
DEC70	0.82	1.4	0.73	0.37	0.098	0.075	0.069	0.065	0.064	0.063	0.061	0.041
1970	7.3	13	6.7	3.6	0.88	0.6	0.53	0.5	0.49	0.48	0.46	0.38
JAN71	0.75	1.2	0.59	0.25	0.065	0.037	0.03	0.026	0.025	0.024	0.022	0.011

Table A.8. Occupational Representative Individual - Red Bone Marrow Equivalent Dose (millirem per year)

Year	Location 1	2	3	4	5	6	7	8	9	10	11	12
1950	4.8	9.6	6.6	4.6	3.8	3.2	3	2.8	2.7	2.5	2.3	1.8
1951	4.7	9.2	6.2	4.5	3.5	2.8	2.5	2.4	2.3	2.1	1.8	1.3
1952	7	13	9.1	6.4	4.8	3.8	3.4	3.2	3.1	2.7	2.4	1.8
1953	9.7	18	12	7.8	5.4	4.3	3.8	3.6	3.4	3	2.7	1.7
1954	10	19	11	7.1	3.8	3.6	3.5	3.3	3.3	3.2	3.1	2.4
1955	14	25	15	9	4.6	4.4	4.3	4.1	4	3.9	3.8	2.7
1956	15	27	16	9.6	4.8	4.6	4.4	4.2	4.1	4	3.8	2.9
1957	27	46	25	14	6.1	5.8	5.6	5.2	5.1	4.9	4.8	3.7
1958	29	51	28	16	6.5	6.1	5.8	5.4	5.2	5	4.8	3.6
1959	27	48	28	17	6.1	5.6	5.3	5	4.8	4.6	4.4	3.5
1960	47	80	43	24	8.6	8	7.7	7.2	6.9	6.7	6.4	4.8
1961	38	65	36	21	8.9	8.5	8.2	7.6	7.4	7.1	6.9	5.3
1962	38	66	36	20	8.9	8.4	8.1	7.6	7.4	7.2	7	5.7
1963	30	50	26	14	4.1	3.8	3.6	3.3	3.2	3	2.9	2.3
1964	32	53	27	14	4.3	4	3.7	3.5	3.3	3.2	3	2.3
1965	22	37	20	10	3.3	3	2.8	2.6	2.5	2.3	2.2	1.8
1966	19	32	16	8.9	2.6	2.5	2.3	2.2	2.1	2	1.9	1.5
1967	19	32	17	9.9	3.4	3.2	3	2.9	2.8	2.6	2.5	2
1968	14	25	13	7.4	2.3	1.8	1.7	1.6	1.6	1.5	1.5	1.1
1969	8.8	15	8.8	5.3	1.6	1.2	1	0.97	0.96	0.93	0.9	0.76
1970	6.3	11	5.7	3.1	1	0.81	0.74	0.69	0.68	0.67	0.65	0.53
1971	0.64	1	0.5	0.22	0.079	0.054	0.044	0.039	0.038	0.035	0.032	0.017

Table A.9. Occupational Representative Individual - Lower Large Intestine Equivalent Dose (millirem per year)

	Location											
Year	1	2	3	4	5	6	7	8	9	10	11	12
1950	44	90	64	45	38	32	28	27	25	22	17	8.2
1951	37	75	54	40	34	28	25	24	23	19	16	7.2
1952	49	99	72	52	43	35	30	29	27	23	17	8
1953	66	130	91	63	44	35	31	29	28	24	18	7.8
1954	69	130	87	57	21	18	16	16	15	13	11	6.4
1955	83	160	100	68	24	20	18	18	17	15	13	6.7
1956	86	170	110	68	24	21	19	18	17	15	13	7.5
1957	130	250	150	91	28	24	21	19	17	15	13	7.4
1958	130	250	150	91	27	23	20	17	15	13	11	6.6
1959	77	150	93	61	21	18	16	15	13	12	10	6.4
1960	120	230	140	86	26	22	20	18	16	14	12	7.6
1961	94	170	100	65	21	18	17	15	13	12	11	7.1
1962	82	150	93	56	21	18	17	15	14	13	12	8.1
1963	71	130	79	48	14	12	11	9.3	8.1	7.1	6.2	3.9
1964	80	150	88	50	15	13	12	10	9.1	8	6.9	4.2
1965	55	100	61	35	12	9.9	8.9	7.9	7	6.3	5.4	3.5
1966	38	69	40	24	6.5	5.6	5.1	4.5	4	3.6	3.2	2.1
1967	41	76	45	28	9	7.9	7.2	6.4	5.7	5.2	4.5	3
1968	33	62	37	23	7.2	4.2	3.3	3	2.7	2.5	2.2	1.5
1969	20	37	23	15	4.9	2.4	1.7	1.6	1.5	1.4	1.3	1
1970	15	29	18	11	3.2	1.5	1.1	0.99	0.94	0.9	0.85	0.65
1971	1.7	3.1	1.7	0.81	0.24	0.093	0.06	0.052	0.049	0.045	0.04	0.019

Distribution

No. of Copies		No. of Copies	

Offsite

Technical Steering Panel

D. S. Barth
University of Nevada
4505 Maryland Parkway
Las Vegas, NV 89154

W. A. Bishop
P.O. Box 47651
Olympia, WA 98504-7651

M. L. Blazek
Oregon Department of Energy
625 Marion Street N.E.
Salem, OR 97310

G. G. Caldwell
Tulsa City-County Health Dept.
4616 East 15th Street
Tulsa, OK 74112

S. N. Davis
Dept. of Hydrology and Water Resources
Building 11
University of Arizona
Tucson, AZ 85721

N. J. Germond
224 Iron Mountain Blvd.
Lake Oswego, OR 97034

P. C. Klingeman
Civil Engineering Dept.
Apperson Hall 202
Oregon State University
Corvallis, OR 97331-2302

K. J. Kopecky
Fred Hutchinson Cancer Research Center
1124 Columbia Street
Seattle, WA 98104

P. D. McGavran
Dept. of Health and Welfare
450 W. State Street, 4th Floor
Boise, ID 83720-5450

R. L. Morrill
Dept. of Geography, DP-10
University of Washington
Seattle, WA 98195

A. H. Murphy
c/o Max Planck Institute for Meteorology
Bundesstrasse 55
20146 Hamburg
Germany

D. W. Price
Agricultural Economics
Hulbert Hall Room 211
Washington State University
Pullman, WA 99164-6210

M. A. Robkin
Radiological Sciences, SB-75
University of Washington
Seattle, WA 98195

G. S. Roessler
Route 1, Box 139H
Elysian, MN 56028

B. Shleien
2421 Homestead Drive
Silver Springs, MD 20902

No. of
Copies

A. P. Slickpoo, Sr.
809 Nez Perce Lane
P.O. Box 311
Kamiah, ID 83536

J. E. Till
Route 2 Box 122
Neeses, SC 29107

D. E. Walker, Jr.
P.O. Box 4147
Boulder, CO 80306

Other

2 DOE Office of Scientific and
Technical Information
Technical Information Center
P.O. Box 62
Oak Ridge, TN 37830

B. Aripa
Environmental Trust
Colville Conferated Tribes
P.O. Box 150
Nespelem, WA 99155

D. M. Beck
U.S. Department of Energy
1000 Independence Avenue
Room 5B301, M.S. EM-5
Washington, D.C. 20585

D. Bonga
Kalispel Tribe
P.O. Box 39
Usk, WA 99180

B. G. Brooks, EH-421
Room J-112
U.S. Department of Energy
Germantown, MD 20545

No. of
Copies

18 K. CharLee
Technical Support and
Public Information
P.O. Box 47651
Olympia, WA 98504-7651

J. P. Corley
2213 Torbett
Richland, WA 99352

L. E. Denham
Centers for Disease Control
and Prevention
4770 Buford Highway N.E., F-35
Atlanta, GA 30341-3724

DNR Hanford Projects
Attn: J. R. Wilkinson
Confederated Tribes of the Umatilla
Indian Reservation
P.O. Box 638
Pendleton, OR 97801

M. R. Donnelly
Public Health Service
Centers for Disease Control
and Prevention
2201 Sixth Avenue, RX-22
Seattle, WA 98121

D. Ernst
Planning Department
Spokane Tribe
P.O. Box 100
Wellpinit, WA 99040

L. L. German
2245 Oxford Road
Columbus, OH 43221

No. of Copies

H. A. Haerer
Golder Associates, Inc.
4104 148th N.E.
Redmond, WA 98052

R. Jim
Confederated Tribes and Bands of the Yakima Indian Nation
P.O. Box 151
Toppenish, WA 98948

D. Powaukee
Nez Perce Tribe
P.O. Box 365
Lapwai, ID 83540

M. Queahpama
Vital Statistics
Confederated Tribes of the Warm Spring Reservation
P.O. Box C
Warm Springs, OR 97761

M. C. Richmond
Department of Civil and Environmental Engineering
Washington State University
Pullman, WA 99164-2910

L. Seyler
Coeur d'Alene Tribe
Plummer, ID 83851

J. C. Simpson
Golder Associates, Inc.
4104 148th N.E.
Redmond, WA 98052

M. Squeochs
Confederated Tribes and Bands of the Yakima Indian Nation
P.O. Box 151
Toppenish, WA 98948

No. of Copies

L. Stembridge
HEAL
1408 West Broadway Avenue
Spokane, WA 99201-1902

W. L. Templeton
2331 Enterprise Drive
Richland, WA 99352

J. P. Thomas
HHIN Resource Center
1719 Smith Tower
506 Second Avenue
Seattle, WA 98104

Onsite

6	**DOE Richland Operations Office**	
	R. F. Brich, TSD	A5-55
	Public Reading Room (5)	H2-53
41	**Battelle, Pacific Northwest Laboratories**	
	D. M. Anderson	K8-15
	G. L. Black (5)	B1-34
	S. D. Cannon	B1-34
	D. E. Deonigi	K8-11
	P. W. Eslinger	K6-52
	W. T. Farris (10)	K3-54
	M. D. Freshley	K6-77
	R. O. Gilbert	K7-34
	W. A. Glass (2)	K3-53
	R. H. Gray	B1-34
	S. P. Gydesen	P8-55
	G. L. Harvey	K2-02
	C. M. Heeb	K8-34
	T. A. Ikenberry	K3-54
	R. E. Jaquish	B1-34
	E. B. Liebow	HARC
	B. A. Napier	K3-54
	J. V. Ramsdell	K6-55

No. of Copies			No. of Copies		
	D. B. Shipler	B1-34		W. H. Walters	K6-60
	S. F. Snyder	K3-54		Publishing Coordination	K1-06
	S. A. Stage	K6-55		Records Center (2)	K3-70
	M. E. Thiede	K6-52		Technical Library (2)	P8-55